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THE EFFECTS OF
CONCENTRIC, ECCENTRIC AND ISOMETRIC TRAINING METHODS
ON LEG EXTENSOR STRENGTH

by



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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "The Effects of Concentric, Eccentric and Isometric Training Methods on Leg Extensor Strength," submitted by Richard Raymond Danielson in partial fulfilment of the requirements for the degree of Master of Arts.

ABSTRACT

A study was undertaken in order to compare the relative efficacy of concentric, eccentric and isometric training on strength of leg extensor muscles. Subproblems investigated were the rate of training for each of the 3 groups, the establishment of concentric, eccentric and isometric strengths of leg extensors and the formulation of equations for predicting any one strength from one of the other two.

Three groups of 10 University of Alberta freshmen participated in and completed a training and testing program over a period of 9 weeks, 7 weeks serving as training sessions. Four tests were given throughout the course of the experiment; concentric, eccentric and isometric strength being measured during each test. During the first 3 training sessions, all subjects executed 6 contractions of the type assigned to their respective groups and by the eighteenth training session, they executed 18 training contractions per session. Training occurred on an average of 3 times weekly for all subjects; usually Monday, Wednesday and Friday.

Subject data was subjected to analyses of variance and the leg strength data was subjected to 3 analyses of variance; one for concentric strength over the 4 test periods, one for eccentric strength and one for isometric strength. The analyses for concentric and eccentric strength

were conducted on average force (lbs.) of 2 contractions at knee angles of 80 to 140 degrees inclusive. The analysis for isometric strength was conducted on average force at knee angles of 70, 110 and 150 degrees respectively. Each analysis was of a split-plot design with 2 factors between and 2 factors within subjects. Sheffe's test for multiple comparisons was applied to all significant interaction mean squares.

Results indicated that the 3 training groups did not differ significantly in mean age, height, initial weight, final weight, upper leg length, lower leg length, initial leg girth or final leg girth. Subjects increased significantly in weight. Both the concentric and eccentric training groups increased significantly in leg girth (cm.) over the course of the experiment, while the isometric group did not increase significantly.

Both concentric and isometric strength could be described more advantageously by a quadratic than by a linear equation linking average force with knee angle. Eccentric strength could be described equally well by either a linear or quadratic equation. Average eccentric strength over angles of 60 to 150 degrees inclusive was found to be 87.07% greater than average concentric strength over the same 10 angles. Average isometric strength over the angles of 70, 110 and 150 degrees was found to be 92.09% greater than average concentric strength and 0.16% less than average

eccentric strength over the same 3 angles.

Eccentric and concentric strength at angles 80 to 140 degrees inclusive, as well as eccentric and isometric strength at a knee angle of 110 degrees were found to be essentially unrelated as indicated by their small amount of common variance (less than 20%). Concentric and isometric strength at 110 degrees were better related (45.14% common variance) indicating that prediction from one to the other at that angle would be possible.

Results of the concentric analysis showed that the eccentric and isometric training groups both increased significantly at the .05 level in mean concentric strength. The concentric training group showed a decrease in performance from test 3 to test 4 and did not increase significantly over the experiment. The isometric training group was found to produce the optimum rate of mean strength increase over the first 5 weeks of training after which the eccentric training group proved to be as effective as that group.

All groups increased significantly in mean eccentric strength over the 7 weeks of training. Although the mean strength for the concentric training group was found to be significantly greater than the mean for the other 2 over the first 3 tests, it was seen by inspection that the linear slopes of the concentric and isometric training groups were similar and greater indicating that these 2 methods of training provided faster rates of eccentric strength increase

than did isometric training.

The concentric and isometric training groups increased significantly in mean isometric strength over the 4 test periods. The eccentric group did not increase significantly in mean isometric strength, but did not differ significantly from the other 2 training groups with respect to rate of strength increase. It was concluded that all 3 training methods are equally effective in increasing isometric strength.

In all 3 methods of measuring strength, it was seen that the greater knee angles showed training effects more than the lesser knee angles.

The general conclusion of the study was that isometric training proved to be the most advantageous in improving strength measured concentrically, eccentrically and isometrically. Specificity of training effects were not seen in the present study.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

Adequate muscular strength is basic to all physical activity. The function of strength in human movement is as yet only partly explained; still it seems fair to assume that muscular strength is as necessary for running, jumping, climbing, throwing, tumbling, catching and hitting as the eyes are for seeing. Both the muscle and the eye perform some function in order to arrive at a human phenomenon (vis. movement and sight); but still other mechanisms, the neuromuscular coordination system and the visual centers in the brain, continue the actions to their completion. Thus the basic premise in this study is that strength is quite necessary for physical activity and that an increase in strength results in somewhat more effective movement.

Morpugo, as reported by Steinhaus (62), found that exercise in the dog produced an increase in the size of the muscle but no increase in the number of muscle fibers. He concluded that this hypertrophy was a result of the exercise. He later concluded, that the hypertrophy thus found as a result of exercise was due to an increase in the intensity or rate of the work done rather than to the total amount.

DeLorme (17) in 1945, devised a method by which atrophied muscles could be restored to normal size and power

by means of exercise with heavy weights. The system consisted essentially of a progressive increase in the weight to be lifted through the full range of motion of the joint. Due to the increase in the weight, the muscle was required to work harder and consequently adapted to the stricter requirements through an increase in the size and strength. The most dramatic increases were found in the extensors of the knee.

It has been shown that isometric strength of muscles is greater than isotonic strength (24, 31, 1). In 1953, Hettinger and Muller (29) reported a system of muscle training on the lower arm extensors and flexors. It involved very little time and little or no change in the length of the muscle, but resulted in an increase of muscle strength of five per cent per week as a result of one static contraction held for six seconds at two-thirds maximum tension. The obvious advantages of this method over the DeLorme method with regard to time involved, equipment needed and instruction requirements resulted in a great many studies comparing isometric and isotonic training methods (4, 6, 9, 10, 19, 20, 45, 48, 51, 54, 57, 63).

However, it has also been shown that the eccentric tension produced by muscles; i.e. the tension that results when a contracting muscle resists an externally applied stretch, is greater even than isometric tension (2, 30, 20, 59, 53). The question then arises: If the eccentric tension produced by muscle is greater than both the isometric and

concentric tensions, is it possible to further increase the demands on the muscle by training it eccentrically and by so doing, increase the strength more than that resulting from isometric training?

The Problem

Physical fitness is many things, muscular strength being only one component. Because strength plays a role in physical fitness, it is important to be able to adequately measure it. Previously, only isometric strength tests have been used to measure strength. This has been done on the basis of two valid reasons. One is that in isometric testing the positioning of the body parts can be standardized, and the other is that when a movement is involved in the test (e.g. pedaling a bicycle or lifting a weight off the floor), muscular endurance and skill are brought into play. However, most of the movements of man are isotonic in nature and the validity of predicting isotonic strength from isometric tests must be questioned. The purpose of this study was to determine which of three possible types of muscular training--by concentric, eccentric or isometric contractions, produces the optimum development of strength at the fastest rate of increase. Also, by comparing the amount of strength increase isotonically as a result of training isometrically and vice versa, the validity of strength tests in use today could be investigated.

The muscles used in the experiment were the extensor

group of the knee, i.e. the rectus femoris, vastus lateralis, vastus intermedius, vastus medialis; the extensors of the hip--gluteus maximus, biceps femoris, semitendinosus and semi-membranosus; and the plantar flexors of the foot--soleus and gastrocnemius.

Subproblems

A number of sub-problems arose out of the major problem. These are:

1. The measurement of the rate of increase of the strength as a result of the three types of training. This was done by measurement at two-week intervals as well as at the start and end of training.
2. The measurement of the ultimate increase of strength due to the 3 types of contractions. This was done by comparing the final strength with the initial strength.
3. The comparison of strength increases (e.g. isometric with concentric). This was done by comparing strength increases of each group both in their individual training contractions as well as the other 2 contractions. The same procedure was followed for all 3 groups.
4. The establishment of the maximum concentric, eccentric and isometric forces of the leg extensors at different knee angles--both before and after training. This has already been done for the arm extensors and flexors (50).
5. The establishment of equations for predicting the eccentric, concentric and isometric forces given one or both

of the others. This would be of assistance both to persons working in the fields of physical education and rehabilitation. Determining one of the forces, would enable one to predict the others with some degree of precision.

Definition of Terms

For the purpose of this study, the following definitions apply:

1. Eccentric contraction: A muscle contraction in which the contracting muscle is lengthened due to an externally imposed force. It is sometimes called breaking strength.
2. Concentric contraction: A contraction in which the muscle shortens its length.
3. Isometric contraction: A contraction in which the length of the muscle does not change.

Limitations of the Study

By necessity, the study is limited by:

1. The sample of students used in the experiment. Only 39 subjects were used due to the time available for testing. The 39 subjects were selected randomly from all faculties except Engineering and Physical Education.
2. The complexity of the movement and the number of muscle groups involved. It should be noted that in all gross-body movements, more than one group of muscles act on the desired limb, so the limitation in this study is not unusual.
3. Motivation and learning in the subjects.

Delimitations of the Study

The following delimitation applies to the study:
Major consideration was given to the efficacy of the 3 methods in producing upward thrust of the legs. The movement here investigated was that involved in going from a squat position to a stand and vice versa.

CHAPTER II

REVIEW OF THE LITERATURE

Neuromuscular Action

Skeletal muscle is made up of very large numbers of muscle fibers each 1 to 120 millimeters long and 10 to 100 microns in diameter (7). Each cell has a thick outer covering called the sarcolemma. Surrounding all the cells is the sarcoplasm which contains many nuclei and elastic fibers. When a cell increases in size through exercise, it is believed that fibers in the sarcoplasm also increase in size.

Muscle contraction occurs in the presence of a neural impulse. Excitation waves from the central nervous system are propagated along the neuron fiber, across the neuromuscular junction and finally along the muscle fibers. The excitation is the stimulus which activates the contractile mechanism (43). From 1 motor neuron there may be up to as many as 100 muscle cells. Often, there are up to 160 muscle fibers in 1 motor unit in the skeletal muscles of mammals. The nerve endings for the motor units are confined to 1 or several zones; the zone is usually in the middle of the muscle fibers (11).

Huxley (36) has postulated that muscle contraction, which in separate motor units is an all-or-none contraction, is due to thin filaments of actin sliding past thick filaments of myosin. The energy requirement is met by breakdown of adenosine triphosphate (ATP).

Muscle Contraction

It has long been known that when a muscle is stretched there is seen a conspicuous rise in the resting heat production. Feng (24), in 1932 stretched an isolated frog sartorius muscle and found that:

. . . with a small initial load stretching has a warming, and releasing has a cooling effect; increasing the initial load completely reverses the phenomena (24:460).

He concluded that the thermo-elastic properties of a muscle depend on the initial load. Hill (31) later found that there was a release of heat occurring in shortening muscle but that the total heat released was proportional to the total shortening. He found that there was a high speed of shortening and a large increment in the heat rate associated with a small load. The opposite effect was associated with a large load.

These observations were confirmed by Abbot et al. (1) in 1951. They also noticed that when a contracting muscle was forcibly extended or stretched, there appeared to be great resistance to stretch and there also appeared to be very little heat produced in the muscle itself. They suggested that the heat could have been absorbed as chemical energy.

Pursuing this hypothesis further, Hill and Howarth (32) stimulated and then stretched the sartorii of toads. They recorded heat and tension separately and simultaneously, and found that the contracting muscles resisted the stretch with

as much as twice the force of maximal isometric tetanus. They believed the energy liberated by a shortening muscle consisted of the work itself and a "heat of shortening" (32:169). They found again that the extra heat normally liberated by a shortening muscle was absent when the muscle was stretched. They concluded by stating that:

The results described above leave no doubt that mechanical work applied to a contracting muscle while stretching it, may reduce the net energy liberated by the muscle itself, either to nothing, or to an amount much less than that in a similar contraction without stretch (32:182).

In a later report (30), Hill gave an explanation for the greater tension developed when a muscle was being forcibly lengthened than when it was allowed to shorten. When the muscle is transformed from a resting state to an active state, there occurs a production of heat called heat of activation "A". If the muscle is allowed to shorten, extra heat is liberated along with the accomplishment of work. The heat liberated is dependent only on the amount of shortening. If "a" is the constant of the dimensions of force and "x" is the amount of shortening, then heat is represented by "ax". The third phase is the accomplishment of work "W". Therefore the total energy produced by the muscle = $A + ax + W$. The greatest mechanical output would result when $\frac{A+ax}{W}$ were as small as possible. When a contracting muscle is stretched, very little heat is released thereby making the above ratio of work to heat smaller and increasing the mechanical output.

He went on to state that there is a contractile component in the muscle itself, its tendon or in the recording apparatus. When, during a stretch, the contractile component is stretched the absorption of energy occurs. The absorption of energy is nothing but a purely physical phenomenon seen for example when a wire is stretched. The temperature of the wire falls during the stretch and rises when it is released. Because the muscle exerts a greater force when it is stretched than when it is allowed to contract, fewer muscle fibers are needed to produce a given force.

Asmussen (5) calls the work done by a muscle when it is forcibly stretched, negative work. He states that ". . . as little as one-third of the number of active muscle fibers are necessary for performing negative work that is quantitatively equal to positive work" (5:173). He defines positive work as that done when a muscle shortens or contracts concentrically. He states that a fiber lengthening in eccentric work necessarily produces more force than when it is shortening because of the relatively fewer number of fibers needed to hold the load.

A practical example of the energy costs of concentric and eccentric work was presented by Abbot et al. (2) in 1952. Two bicycle ergometers were joined by means of a common chain so that one bicycle was pedaled forward and the other had to be pedaled backward to ensure movement of the chain. Actually, one subject pedaled forward at a certain rate and the other pedaled forward with slightly less force in order to resist

the movement. The movements involved were identical with respect to muscle groups involved. The concentric cyclist pedaled at a speed set by a metronome and the other exerted a force as indicated by a gauge. The two cyclists did the same amount of work, as both bicycles were joined together. It was found that the cyclist pedaling eccentrically always did less work as measured by oxygen consumption, and was never as subjectively tired as the other. Abbot concludes by saying: "The physiological cost of negative work is considerably less than that of positive work, and the difference increases with speed of movement" (2:388).

In order to increase the amount of positive work done by a muscle, Cavagna et al. (12) in 1965 stretched an isolated frog gastrocnemius immersed in Ringer's solution at 0 degrees centigrade and allowed it to contract. They observed contractions of 3.94, 4.65 and 13.04 gram-centimeters respectively after intervals from 0 seconds to 5 seconds between stretch and release and concluded that there is greater mechanical efficiency if a muscle is stretched before it is required to do positive work.

Rasch (50) measured forces developed by the elbow flexors in isometric and isotonic contractions. He used 24 male students and measured strength after the subjects had undergone a six-week training program exercising 3 days a week. Half of the subjects trained with the left arm and half with the right. A strain gauge dynamometer measured isometric strength and the 1 repetition maximum determined

isotonic strength. He found the mean isometric tension to be 43.2 pounds, S.D. 3.4 pounds and the mean isotonic tension to be 41.8 pounds S.D. 6.9 pounds. No statistically significant difference was seen between the two.

Rasch and Pierson (53) in a further study, compared maximum isometric tension and breaking strength tension. Eighteen male subjects were tested at an angle of 90 degrees (isometric test) and from an angle of 90 to 80 degrees of elbow flexion (breaking strength test). The mean isometric tension was 49.5 pounds and the mean breaking strength tension was 50.9 pounds with no significant difference between them. He concluded, "On the basis of this and the previous study, it would appear that isotonic, isometric and breaking point strength tests give similar results" (53:535).

Doss (20) devised a method by which continuous recording of concentric and eccentric forces could be conducted. He administered three tests to 37 male Physical Education juniors ages 19 to 23. The tests consisted of concentric, eccentric and isometric elbow flexion in the standing position from an angle of 75 to 165 degrees. The movement took approximately 18 seconds to complete. He found that for the full range of motion eccentric force was significantly greater than concentric force. The average eccentric force was 13.5 per cent greater than the average isometric force and the average isometric force was 32.1 per cent greater than the average concentric force. These differences were significant at the .01 level of confidence.

The problem of human error in the dynamometer was eliminated by Singh and Karpovich (61) when they constructed an electrically operated dynamometer capable of measuring force continuously. They stabilized the subject in a chair and standardized the movement. Elbow angles of 40 to 150 degrees were continuously and simultaneously recorded with the forces of the three contractions by means of an electrogoniometer (38) and strain gauge. They found that according to measurements taken on 20 Physical Education students, eccentric force of flexors was significantly greater at the .01 level than the isometric and concentric forces throughout the range of movement. The eccentric force of the extensors was not significantly greater than the isometric force from 60 to 80 degrees and was significantly less than the isometric force from 120 to 140 degrees. From 50 to 110 degrees of elbow extension the eccentric force was significantly greater than the concentric force and significantly less at angles of 130 degrees and 140 degrees.

Early Studies of Isotonic Strength Training

DeLorme (17) presented a method in 1945 by which muscle strength and hypertrophy could be gained. Working with hospital patients he found that periodic exercise, in which the muscle contracted concentrically, resulted in increased strength and hypertrophy. With respect to exercise of weak muscles he was firm in his opinion;

We firmly believe, on the basis of our clinical observations, that even atrophied musculature must be submitted intermittently to maximum loads, in order to attain maximum hypertrophy (17:651).

Patients exercised on a table where, by means of pulley arrangements, most muscle groups could be involved. Once a week the subjects' capacity for lifting maximum weight was determined. This was termed the one repetition maximum (1 RM). The 10 repetition maximum (10 RM) was also determined, this being the weight the subject could lift only 10 times. He used 300 patients as subjects, and required them to complete 7 to 10 sets of 10 repetitions each per day for the remaining days of the week. Each week a new 1 RM and 10 RM respectively was determined and the sequence was repeated. The exercises were designed so as to be progressive with respect to return of power and motion. Increases of strength and hypertrophy were found and the only after-effects noticed were symptoms of thigh soreness.

Three years later DeLorme (18) modified his method so that only 3 sets of 10 contractions per day were recommended. The first set of 10 repetitions was completed with 50 per cent of the 10 RM, the second set with 75 per cent of the 10 RM and the third with 100 per cent. Each week, however, the 1 RM and the 10 RM were determined as before.

DeLorme's basic method was tested widely by physiotherapists, and physicians working in the rehabilitation field. Krusen (40) working with patients with quadriceps weakness due to polio, modified the system so that 1 RM and

5 RM were used. There were 2 sets of 15 repetitions completed per day. Dividing his patients into an overloading and an underloading group he exercised them 5 days per week for a period of 12 weeks. He found that there was significant improvement of strength for both groups with no signs of levelling off, but that there was no significant difference between the two groups.

Isometric Exercises

Muscle increases in strength due to increased demands. In discussing the application of the overload principle to man, Hellebrandt (26), states that ". . . no effort of the will can recruit more motor units than the number required by the magnitude of the task" (26:282). This is in effect saying that no matter how much training by means of any muscle contraction is undertaken, if more and more work is not put into each successive contraction, no increase in strength will result.

Hellebrandt and Houtz (27) in 1956 conducted an experiment with the object of comparing two types of training which equalled each other in the amount of work required, but were so designed that one type was an overloading regimen, the other an underloading one. Eight male and 9 female Physical Education students were used as subjects. The experiments were conducted on wrist flexion and extension and over 620 were conducted over a period of 4 years. The results showed that the overloading routine resulted in a significantly

greater increase in strength than the underloading routine. They concluded that any contractions which are not of a certain intensity and do not place any strain on the neuromuscular system, have very little, if any, effect on the development of strength in the muscles concerned.

Hettinger and Muller (29) reported in 1953 of a series of experiments in which one isometric contraction of a muscle against an immovable resistance resulted in an increase of muscle strength. Their experiments were conducted primarily on 9 German miners, ages ranging from 22 to 37 years. Muscles tested were the elbow flexor and extensor groups. The maximum isometric strength at 90 degrees flexion was established on one day and the exercises were carried out the next 5 days of the week. Both the magnitude and the number of contractions were varied. The seventh day of the week after the test period was set aside for a rest day. The significant finding of their study was that optimum increase in strength (5 per cent per week) resulted from a single contraction per day for 6 seconds at 67 per cent of the subject's maximal strength. They decided that the stimulus for training was that of lack of oxygen to the tissues.

Muller (47) later elaborated on the stimulus for increase in muscle strength in normal, atrophic and trained muscles. His results are presented on the following page.

Effect on Maximum Strength*

Present State of the Muscle Training Force as Percentage of Maximum Strength

	Less than 20%	20-35%	Greater than 35%
Atrophic	Decreases	Increases	Increases
Normal	Decreases	Remains Constant	Increases
After Intensive Training Period	Decreases	Decreases	Increases

*From Muller (47) 1959

Still later, Muller reported:

A strong contraction is the stimulus which makes a muscle increase its mass, its cross-section and its strength. It obviously makes no difference whether the contraction happens at home, at work, or in a gymnasium; whether one contracts muscles with the special aim to increase muscular strength, or just casually (46:42).

Summarizing the previous 10 years of study, Hettinger reported these findings:

1. It has been shown that muscle tension, i.e. the training strength, seems to be the important point in muscle training.
2. The minimum training stimulus in muscle tension is about 1/3 of the maximum strength obtainable in voluntary isometric muscle contractions, and an exertion of 40 to 50% of the current maximum strength of the muscle gives the muscle maximum obtainable training effect.
3. It is unnecessary to keep up this tension to the point of complete fatigue of the muscle to get the maximum in training effect. A period representing 10 to 20 per cent of the time it takes to reach complete fatigue of the muscle--which prevents further holding of muscle tension--is enough to reach the maximum obtainable training effect.
4. One single training stimulus per day is adequate for the maximum obtainable training effect for a certain muscle group, in a certain individual, during a certain time. (28:75).

Studies of Isometric and Isometric vs Isotonic Training

Crakes (15) duplicated Hettinger and Muller's study with elbow flexors using the same apparatus for measuring static strength in the standing position. His subjects were 50 Law students from the University of Oregon. All subjects trained at one contraction per day at 67 per cent of maximum strength. Saturdays were set aside for testing and recording of new maximum strength. He tested for 9 weeks but discarded the first 2 weeks of data because of irregularities, and the last week because of absenteeism (exam week). In the middle 5 weeks he found a mean increase of strength of 6.00 pounds. This was significant at the .01 level of confidence and turned out to be an average increase of 2 per cent per week. He concluded that his results generally supported those of Hettinger and Muller and that this method could not be called the most effective, but one of the most effective means of increasing strength.

Rarick and Larson (49) compared a single daily six-second bout at $2/3$ the maximal tension with from 5 to 8 bouts at 80 per cent of maximal tension. The second group performed 5 bouts on Mondays and a maximum of 8 bouts on Thursdays. They found that the more frequent exercise group showed greater absolute and relative gains and had greater strength retention than the single bout group. There was, however, no significant difference between the two groups. Their experiment generally supported Hettinger and Muller's findings.

Gardner (25), testing the specificity of strength increases, gave isometric exercises of knee extension to 3 groups. One group exercised at 115 degrees of knee flexion, one at 135 degrees and the third at 155 degrees. There were 15 subjects in each group and 15 in a control group. His results showed that all groups improved significantly in strength at the .01 level of confidence over the control. He did, however, find that the strength increases were specific to the position in which the limb was exercised.

Using a horizontal flexion-adduction movement of the right arm, Whitley and Smith (65) also tested the specificity of strength increases due to isometric exercises. Using 31 college male volunteers, they found no significant differences between 6 arm angles of the movement after the subjects had been trained only in the middle of the range of movement.

The problem of employing a static strength test in order to measure changes in strength accruing from dynamic strength training was investigated by Berger (9) in 1962. He used an isotonic and isometric program of increasing back extension strength. The groups were measured statically and dynamically and it was found that they both improved significantly at the .01 level on both measures of strength. However, he reported that:

From the results, if training involves weight lifting where the muscular contractions are primarily dynamic then a dynamic strength test would measure more accurately changes in strength. This would also hold true where static training is followed (9:332).

Rasch and Pierson (51) found similar results in 1963.

Using 27 adult male students, and training them for 6 weeks (3 days per week) isotonically in the two-hand curl, two-hand reverse curl, two-hand military press and the supine bench press. They found that although the subjects did improve in isotonic strength, they did not improve significantly in isometric strength. They state that:

. . . changes in isotonic functioning represent primarily physiological alterations in the circulatory-muscular systems, whereas changes in isometric scores principally reflect alterations in the central nervous system. Thus they do not measure identical aspects of neuromuscular abilities (51:230).

While isometric methods do not seem to present an extremely accurate estimate of isotonic ability, they may be used to predict success or failure in an isotonic task such as bar chinning. Bender (8), in 1966 pretested 128 male subjects ages 10 to 18 for isometric strength of elbow flexors at 3 angles. The actual chin-up was used as an isotonic criterion. The strength/pound body weight was seen to be an accurate predictor of a subject's ability to perform one chin-up.

Asa (4) compared 3 groups; one trained isotonically, the others isometrically but varying in the number of training bouts per day (1 vs. 20 bouts per day), on the strength of the adductor digiti quinti muscle. He found that all 3 types of training produced increases in strength but that the isometric group with 20 bouts daily improved better in strength and endurance than the other two.

A further study by Liberson and Asa (41) on the strength

and endurance of the hypothenar eminence showed that isometric exercises of 6 seconds repeated 1 to 20 times a day were more effective than DeLorme-type isotonic exercises in increasing muscular strength and endurance.

Darcus and Salter (16) studied the elbow pronator and supinator muscles. Two groups made 30 contractions each day 5 or 6 consecutive days each week for approximately 4 to 5 weeks. Twenty-eight training sessions were completed. They found that the dynamic training in general produced better improvement, but they furthered the opinion that these differences could be due to differences in motivation.

Salter (57) compared groups trained with either 2 or 15 isometric supinations of the left hand, with a group trained isototonically with a comparable amount of exercise. Twelve males and 8 females ages ranging from 17 to 48 years were used as subjects. She found that all training procedures resulted in a significant improvement in strength but that there were no significant differences among the 3 groups. She noted that part of the improvement could have been due to the acquisition of skill.

Meadows (45) compared an isotonic group trained for 10 weeks on an all-body program, with an isometric group trained for the same period of time on a similar program. He used experienced football players to see if strength training would result in a significant improvement of skill. Both the experimental groups improved significantly over the control at the .01 level in speed and force of the offensive

football charge, chins, dips, vertical jump, leg lift, and back lift. There were no significant differences between the groups in strength or skill improvement.

Rose et al. (55) tested the effect of isometric contraction on the quadriceps muscle group. The subjects sat on a table with the lower leg vertical to the floor. Weights were strapped to the foot, and the subject attempted to lift the leg until it was parallel to the floor. This position was held for 5 seconds. The amount of weight the subject could hold at 180 degrees of extension for 5 seconds was called the maximal lift. It was found that on 3 groups of subjects--two normal and one subnormal, that each day the subjects could increase the maximal lift by $1\frac{1}{4}$ pounds over the previous day's lift. No greater increments than this could be successively handled. They found that strength could be maintained with decreasing effort, for relatively long periods.

Knee extensor strength training of high school boys in Edmonton was conducted by Richardson (54) in 1963. Sixty grade 10 boys were divided into 3 groups. One group was trained isotonic-isometrically similar to subjects in the study by Rose et al.; the other was trained isometrically at knee angles of 115 degrees and 135 degrees of flexion. He found that the isotonic group increased significantly over the isometric group at the 135 degree angle and that there was no significant difference between the 2 groups at the 115 degree angle. Both groups increased significantly over the control in both strength and endurance or holding time.

Baer et al. (6) using wrist flexion, compared 63 normal subjects trained isometrically, isototonically with high resistance and isototonically with a low resistance complex movement. They measured isometric tension, endurance and reaction time. The isometric group produced better but nonsignificant results with respect to isometric tension and there were no significant differences among the groups with respect to work capacity or reaction time.

Dennison et al. (19) found no significant differences in muscular endurance as measured by chinning and dipping ability of 2 groups, one trained isototonically with a weight training program, the other using the 13 exercises of the Commander Set of isometric exercises. The groups were university students enrolled in the compulsory physical education program and they met twice a week for 8 weeks. Both groups did increase significantly in strength.

Kerr (39) conducted an investigation into the relationship between changes in strength of the quadriceps muscle and changes in reaction time and movement time in a knee extension movement. Subjects were 45 males at the University of Alberta. The students were divided into 3 groups of equal mean reaction time and movement time. One was isometric, one was isotonic and the third was a control. The isometric group practiced on the standard exercise table at knee angles of 115, 135, and 155 degrees. The isotonic group lifted a weight from 90 degrees to 180 degrees 3 times. Both groups increased in strength with no significant differences between them.

Brodin (10) in 1963 compared isotonic-concentric exercises with isometric exercises under conditions which occurred when patients exercised on their own. Two experimental groups of female physical therapy students (isometric-41 and isotonic-44) and 2 groups of controls were tested before and after an 8 week training program in which the experimental subjects trained 5 days per week. The isotonic-concentric group improved 65 per cent on the trained hand over its control and the isometric group improved 20 per cent on the trained hand over its control. He concluded that either the motor units reacted more favorably to the isotonic-concentric exercises, or that the isometric group trained incorrectly.

In order to determine the response of 2 different muscle groups to isometric and isotonic exercise, Ward and Fisk (63) trained 75 male university students (isometric-38 and isotonic-37) 3 times a week for 1 month followed by 1 month's rest followed by 2 weeks additional training. Muscle groups used were the quadriceps and biceps brachii. After training, the quadriceps muscle groups showed greater strength due to isometric training than to isotonic when strength was measured isometrically, and equivalent strength when it was measured isotonically with the 1 RM and 10 RM. The percentage increase in the biceps was less than half that of the quadriceps and results indicated that strength was specific to the type of training. Isometric tests in all cases tended to show the greatest percentage increase in strength.

McGraw and Burnham (44) in 1966 trained 3 groups of 31 subjects each for 9 weeks. One group trained isotonic-ally, one isometrically and the third trained with speed contractions involving light weight or weight of the limb itself. Muscle groups tested were the flexors of the upper arm, extensors of the forearm and extensors of the leg. They found that no single method was adequate in achieving maximum development of strength and endurance but that isotonic and isometric methods seem to be best for those who are strong initially.

Two groups of 26 subjects were trained statically and dynamically while one acted as a control, in a study by Whitley (66) in 1967. He tested the 3 groups isometrically at 6 angles in a horizontal flexion-adduction arm movement both before and after training. He found test-retest reliability coefficients of .85 to .89 on 2 trials per angle. Although both static and dynamic methods produced significant (.05 level) increases in strength (except 12 degree angle for dynamic training), the static method proved to be significantly superior.

Eccentric, Concentric and Isometric Training

Peterson (48) in 1960 conducted an experiment where concentric, eccentric and isometric training were given on arm flexors and knee extensors. He divided 17 young male and 17 young female subjects into 4 groups. Group I of 5 males and 5 females made one isometric contraction per day

on right elbow flexors and knee extensors. Group II of 6 males and 4 females made 10 isometric contractions per day on right elbow flexors and right knee extensors. Group III of 2 males and 4 females made 10 eccentric contractions for the elbow flexors and rode 15 minutes on a bicycle ergometer for the knee extensors. Group IV was a control of 6 males and 7 females. The groups underwent a training period from 20 to 36 days. The results indicated that no significant increase in strength resulted from one isometric contraction per day. Ten isometric contractions per day did increase strength, while 10 eccentric contractions per day did not increase muscle strength. Dynamic work improved muscle strength. No improvement of endurance resulted from the programs.

Singh and Karpovich (60) trained elbow extensors of subjects eccentrically for 20 contractions per day, 4 times a week for 8 weeks. The training included elbow angles of 40 to 150 degrees. Average contraction time was 6.5 seconds. Results indicated significantly greater eccentric gains (.05 level) between angles of 50 and 90 degrees and nonsignificantly greater gains between 100 and 140 degrees. Concentric increases in all angles were statistically significant. The average increase measured eccentrically was 22.9 per cent and that concentrically was 42.8 per cent. They found also, significant gains in concentric, eccentric and isometric strength (100 degrees and 80 degrees) of the antagonistic muscle group.

Problems in Testing Muscle Strength

Howell and Morford (35) identify four types of problems in testing for strength; vis. learning, motivation, specificity and other variables such as sex, body size, changes in posture and equipment used for measuring strength. If any movement other than the most simple motion is used for testing, motor learning will surely occur. Another aspect of learning is the persistence of strength as a learned act. This possibility is mentioned by Hellebrandt and Houtz (27), Rose et al. (55) and Hellebrandt (26).

Differences in motivation due to levels of aspiration, sex, age and such external variables as hypnotism all influence results obtained in strength tests.

Obtaining one result on a strength test and applying it to normal bodily activities appears to be difficult indeed. Royce (56) questions whether better athletic performance is really related to increase in static strength due to isometric training. Strength increases may be specific to the movement tested. Conflicting results have been obtained here. Shaw (58) found a non-significant relationship between strength-in-action and strength/mass ratio in a lateral arm movement. Clarke and Henry state that,

. . . conditioning exercises of the progressive resistance type that do not directly involve a lateral arm test movement apparently cause increased mean speed of the test movement (14:325).

Houtz et al. (34) found that relative movements of the

hips caused differences in the flexion power of the knee joint. Clarke et al. (13) also found a 15.9 kg. difference in the extensor power of the knee due to extension of the hips. Hood and Forward (33) report that the force a muscle does exert is not necessarily the force it can exert.

These studies indicate that in training and testing of muscle strength, there are problems which must be overcome before meaningful results can be obtained.

CHAPTER III

METHODS AND PROCEDURE

Subjects

Subjects for the study were 39 University of Alberta male freshmen students selected at random from all faculties except Physical Education and Engineering. Physical Education students were omitted because of any possible extra training they might receive during their course of study, and Engineering students were omitted because of timetable conflicts with training sessions. Subjects were persons participating in the required physical education program--doing very little physical activity outside of this program. Originally, 39 subjects were to be used in the study, however, 3 subjects in the concentric group and 1 in each of the other 2 were unable to complete the training program. In order to keep the number of subjects equal in all 3 groups, 2 subjects, selected at random from each of the eccentric and isometric groups were deleted bringing the total number of subjects to 30; 10 in each group.

Experimental Equipment

The experimental equipment consisted of the leg dynamometer, a load cell, Beckman dynagraph, Sargent recorder model SR made by E.H. Sargent and Co., a specially designed belt and an electrogoniometer (henceforth called elgon).

The leg dynamometer (Figure 1) consists essentially of a two-horsepower electric three-phase motor connected by means of a flexible coupling to a Vickers eighteen-gallon-per-minute vane pump; from there to a positive filter and from there to a directional control valve which enables a double-acting hydraulic cylinder piston to travel forward, backward or stop. The hydraulic cylinder has a three-inch diameter and a thirty-inch stroke. Connected to the cylinder rod is a three-thousand-pound capacity cable. The cable passes around 2 ball-bearing pulleys so as to leave the machine at a point directly between the subjects' feet, just in front of the medial malleoli. Directly behind the area designated for the subject to stand, is mounted a sturdy plywood backrest extending from 12 inches above the machine to 7 feet. An arborite board is placed so as to help prevent friction. On each side of the backrest are mounted steel rods on which travel ball-bearings. Connected to each ball-bearing is half of a friction-operated safety belt apparatus so that the subject may be strapped to the board but may still move up and down. Instrumentation on the dynamometer includes a start-stop switch, an additional hand-operated start-stop microswitch for safety purposes, a motor-reset switch, an oil filter pressure gauge, a pounds-pull gauge, a lever for regulation of cablespeed, and a directional-control lever. Microswitches at each end of the piston cylinder automatically switch off the machine, as does the hand-operated start-stop

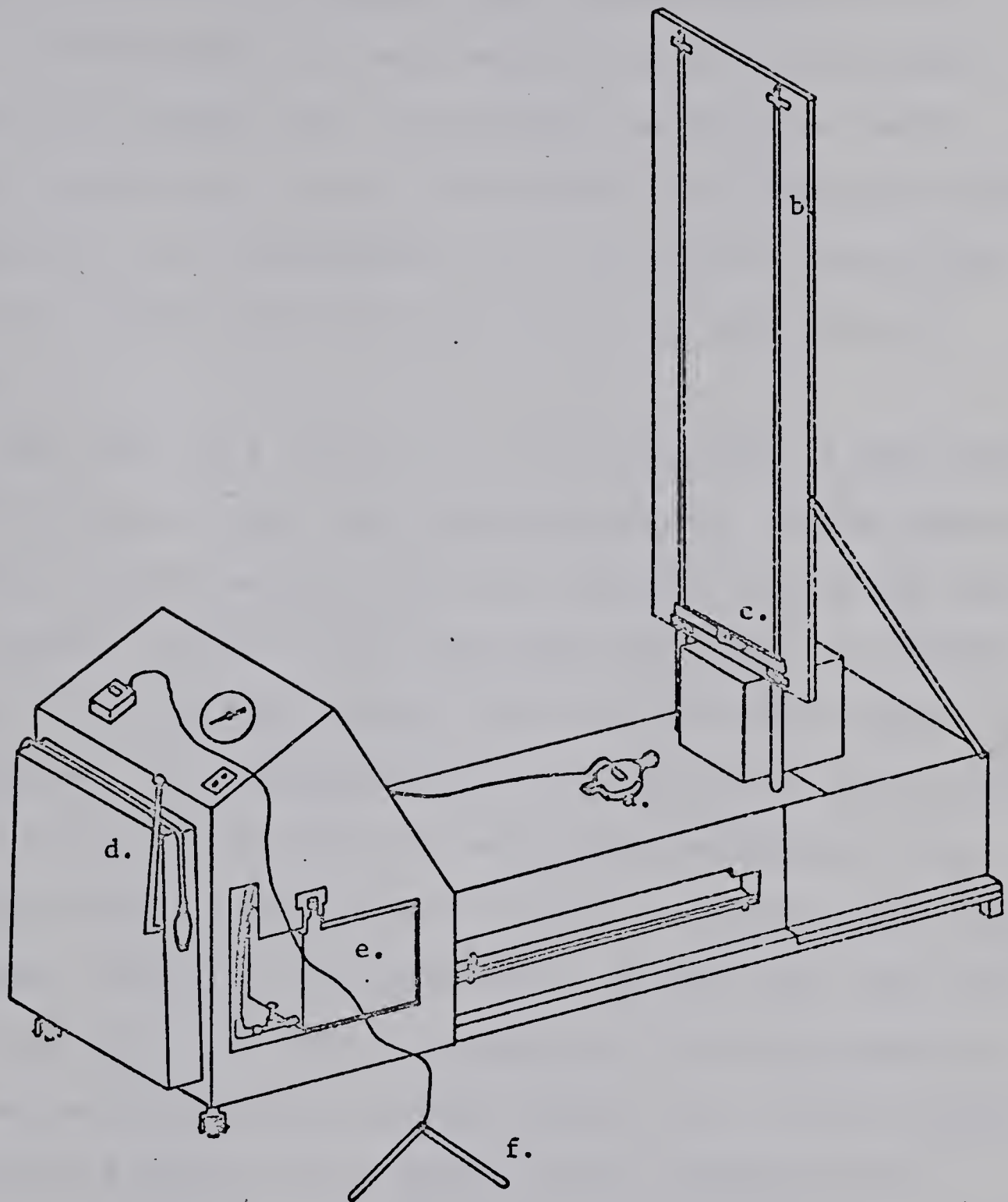


FIGURE 1.

EXPERIMENTAL LEG DYNAMOMETER

- a. Load Cell and Cable b. Vertical Board c. Restraining Belt
 d. Cable Length Adjustment Switch e. Vane Pump
 f. Electrogoniometer

microswitch for safety purposes, a motor-reset switch, an oil filter pressure gauge, a pounds-pull gauge, a lever for regulation of cablespeed, and a directional-control lever. Microswitches at each end of the piston cylinder automatically switch off the machine, as does the hand-operated start-stop switch. Thus there are 2 safety switches incorporated into the machine so as to prevent the subject from being pulled down to a knee angle of less than 50 degrees.

The load cell (Figure 1) is a type UG31, 3,000 pound capacity, tension type from BLH Electronics. It is mounted between the cable and the belt-bar assembly around the subject's waist. Power to and from the load cell is provided through a twin-channel Beckman type RS dynagraph (Figure 2). The dynagraph is connected both to the load cell and to the elgon. Signals from the load cell are received into the dynagraph which is calibrated to move 1 millimeter for every 100 pounds tension on the load cell. At the same time, the signal from the load cell is taken from the dynagraph and amplified on the Sargent recorder (Figure 2). This machine is calibrated so that 100% equals 3,000 pounds and the pounds-pull is read as per cent of 3,000 pounds. Accuracy to within 3 pounds can be achieved by interpolating to tenths of each small division on the Sargent enlarger.

The elgon (Figure 1) is a variable rheostat mounted in a chassis which is able to rotate about the central axis. It

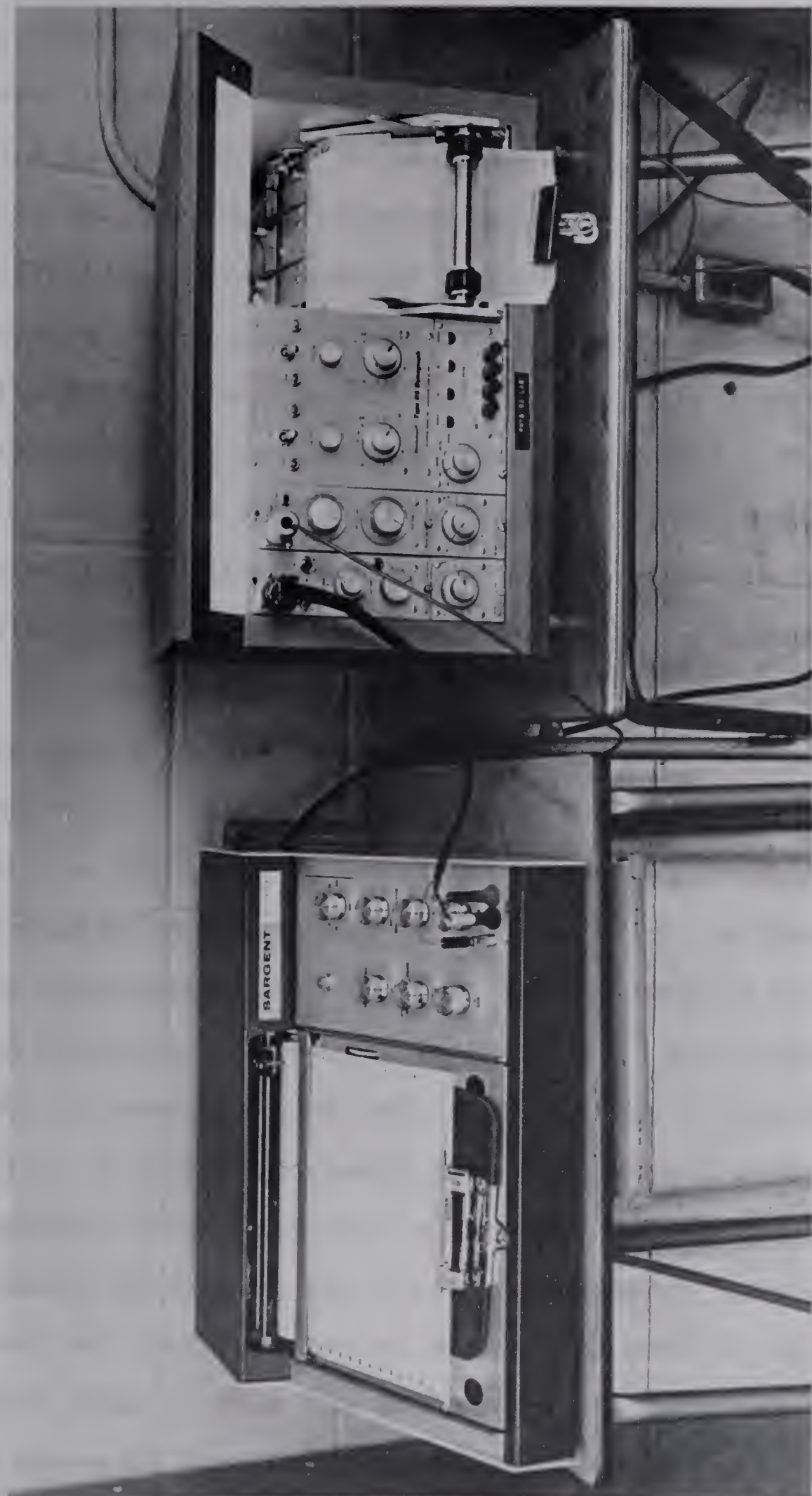


FIGURE 2
SARGENT MODEL SR RECORDER AND BECKMAN TWIN-CHANNEL DYNAGRAPH

has been described by Karpovich (37, 38) with regard to study of movement in joints, but essentially, the change in resistance occurring as the joint is flexed or extended results in a pen deflection on the second channel of the dynagraph. This deflection is adjusted so that 180 degrees produces a deflection to one side of the pen range and 50 degrees produces a deflection to the other side of the pen range. A calibration thus results in approximately 3 millimeters deflection for every 10 degrees of flexion. Thus by comparing the knee angle with the pounds-pull on the dynagraph and then referring to the Sargent recorder, the pounds-pull may be calculated for any angle within the range of movement.

The specially designed belt (Figure 3) consists of a bar with a safety release hook, which is connected to the load cell. The bar is sewn into a 4 inch wide web belt. The belt is tightened by means of a safety release buckle so as to provide a fourth safety feature which is independent of the dynamometer. If the pull of the machine becomes abnormal and the automatic safety features also fail, the subject can both release the load cell from the bar and himself from the belt. In order to ensure that the bar and belt do not slip downward under pressure, a shoulder harness was devised which assists in holding the bar at a specified height (vis. at a level so that the hook on the bar is next to the subjects' pubic bone). Thus the subject is held against the backrest by means of a safety belt and the bar is held at a constant

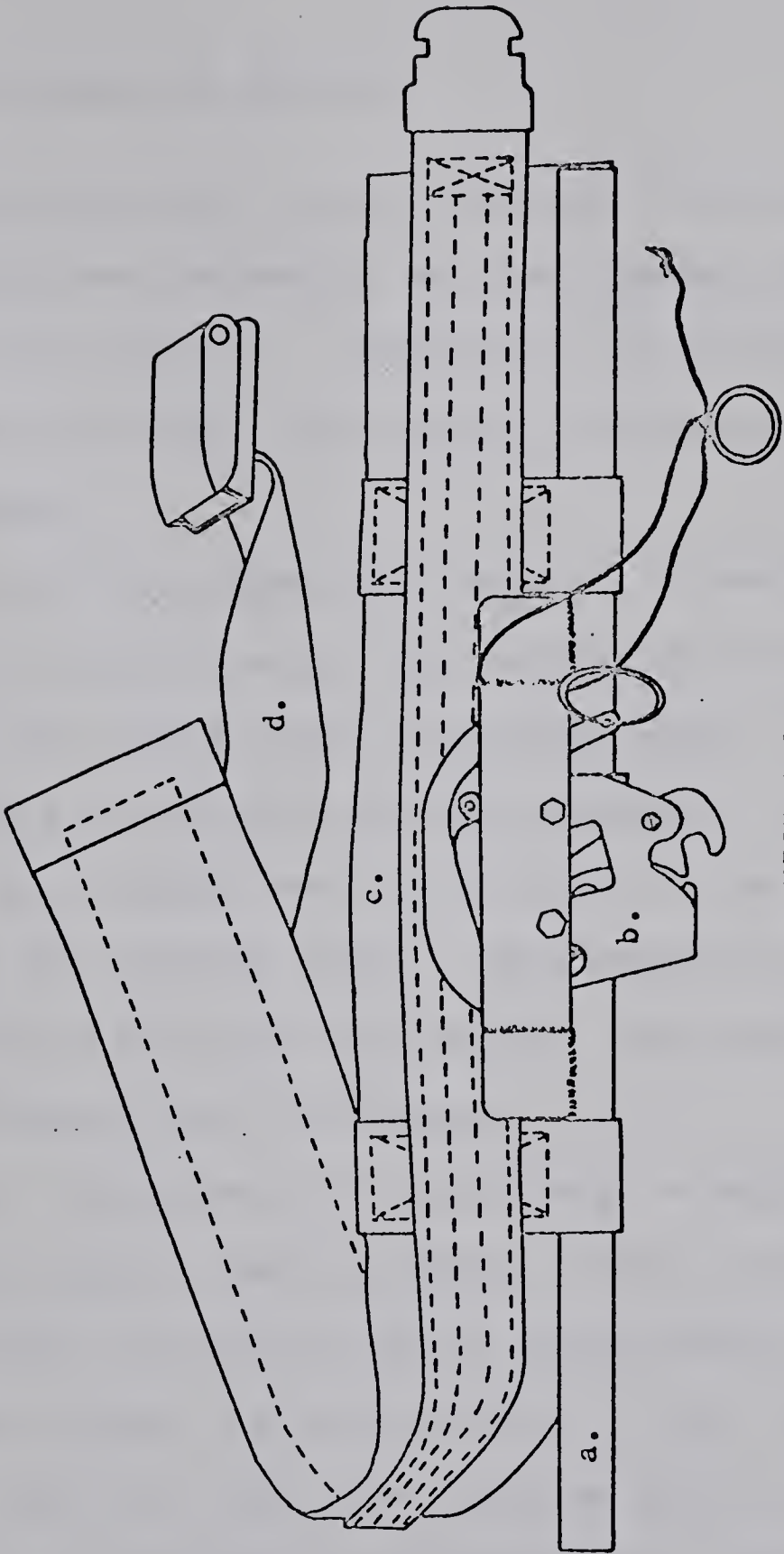


FIGURE 3

EXPERIMENTAL BAR AND BELT

- a. Bar
- b. Safety Release Mechanism
- c. Four-inch Webbed Belt
- d. Automobile Seat Belt.

height at the subjects' waist both by a belt and a shoulder harness.

Preliminary Testing and Safety

Preliminary tests run on subjects indicated that the shoulder harness was necessary so that the bar did not slip when pressure was applied. Similarly, the backrest was added so as to eliminate the balance problem and to standardize the movement.

With regard to isometric testing, it became evident that unless the correct angle was arrived at with the belt system tight, the knees would straighten about 10 degrees before the cable restricted further movement. So it was decided that the subject would be pulled to the proper angle with the belt and harness tight. This seemed to be the answer for stabilizing the knee angle. The lowest knee angle to be measured was 60 degrees.

Because the movement is voluntary, a subject will not apply more resistance than his body is able to withstand. However, in order to ensure safety, the breaking point of the neck of the femur was investigated. Evans (17,18) in 2 studies, has found that the breaking point of the neck of the femur, as indicated by "stress-coat" studies, is less under dynamic loading (i.e. very fast dynamic loading as in dropping a weight on a vertical dry bone) than under static loading. His studies indicated that the neck of a

femur can withstand pressures of up to and exceeding 1280 pounds and since this allows a minimum of twice that for both legs, it is quite unlikely that this presents a problem in this type of study.

Experimental Design and Training

The study lasted for 9 weeks consisting of 2 weeks preliminary testing and 7 weeks of training in which 3 other tests were given. Subjects were also given 3 tests in which oxygen consumption was determined for the groups undergoing their respective training contractions. Each of these sessions was considered as a training session for the purposes of this study. A schematic representation of each subject's training sessions and test periods is presented in Appendix A.

Subjects trained on an average of 3 times per week, usually Monday, Wednesday and Friday. At the start of the experiment, the subjects trained at 6 contractions per session. The number of contractions was increased gradually by 3 until at week 7, 18 contractions per training session were completed. The time for each contraction was 6 seconds, thereby equilibrating the amount of work done by each group. Rest intervals of 15 seconds between contractions were given throughout the experiment. The order of the training angles for the isometric training group was randomized. By increasing the number of contractions, the subjects were required to perform more work as training progressed.

Age, height, weight and leg length (left leg) from the greater trochantur to the lateral epicondyle and from the lateral epicondyle to the lateral maleolus were recorded before the first test. Leg girth was measured with a steel tape at a point midway between the lateral epicondyle and greater trochantur. The subjects were randomly divided into 3 training groups--concentric, eccentric and isometric. The test consisted of 2 concentric and eccentric contractions and 2 isometric contractions at knee angles of 70, 110 and 150 degrees. The various tests were administered in a randomized order in order to balance out the factor of fatigue. The concentric contraction was made from an angle of 60 degrees flexion to an angle of 150 degrees extension and the eccentric contraction was made from an angle of 150 degrees extension to 60 degrees flexion. Average knee velocity for 2 trials each, of both concentric and eccentric contractions for all 30 subjects at the initial test, was 15.11 degrees per second with a standard deviation of 2.82 degrees per second. Since each concentric and eccentric test contraction occurred over 90 degrees, average contraction time was 5.95 seconds as opposed to 6 seconds for the isometric test contractions. The 3 types of contractions therefore, took the same amount of time.

Testing Procedure

Upon entry into the laboratory the subject was asked to put on a pair of shorts. The belt was fastened and the elgon was taped to his leg. Once he was on the machine, the cable length was adjusted. At a signal he attempted his first



FIGURE 4a SUBJECT IN RESTING POSITION



FIGURE 4b SUBJECT UNDERGOING TEST CONTRACTION

contraction (Figure 4b). Shortly before this, both recorders were turned on and remained on for the remainder of the test. Once the subject completed the first 2 contractions as determined by the random order sheet, the experimenters adjusted the cable length for the next 2 contractions. Two experimenters were present for all tests, one operating the leg dynamometer, the other the recording apparatus. A rest of 30 seconds was given between contractions during which the subject was required to sit on the stool provided (Figure 4a). As mentioned before, the subject was pulled to each of 3 isometric angles with the belting system tight so as to keep the knee angle close to the desired angle. After the correct angle was reached, the 30 second rest was begun. For the eccentric test, the subject was cautioned to start the contraction with slightly bent knees. Four tests conducted in this way were given to all subjects throughout the course of the experiment (see Appendix A).

Calibration of the Apparatus

The load cell, dynagraph and Sargent recorder were calibrated simultaneously by comparing the indicated deflection on the 2 recorders with a known load on a Baldwin Universal Testing Machine accurate to 2 pounds. In the Sargent recorder, a 3,000 pound pull was set to 100 per cent and lesser pulls were read as per cent of 3,000 pounds. This was done at the outset and completion of the experiment.

The electrogoniometer was calibrated by taping it to a manual goniometer and noting deflection on the Beckman recorder

for each 10 degrees of rotation about the central axis.

At the start of each testing day, and each time a new electrogoniometer was used, a calibration was made with the manual goniometer. The load cell, dynagraph and Sargent recorder were calibrated at the beginning of the experiment and the termination. The 2 calibrations were the same.

Statistical Treatment

Repeated measures of each knee angle were taken on each subject for each contraction during each test. The data obtained were subjected to 3 split-plot analyses of variance, 1 for concentric strength, 1 for eccentric strength and 1 for isometric strength. Because of missing data at the extreme knee angles, analyses on concentric and eccentric strength were conducted on the knee angles of 80 to 140 degrees inclusive. At these angles, 28 items of data out of 1680 were missing and were replaced with the mean of the respective group. The isometric analysis was conducted on knee angles of 70, 110 and 150 degrees.

Any variance component which was of experimental interest, and in which the treatment mean square was significant, was further analyzed for significant differences using Sheffe's test for multiple comparisons (21:150). This is a conservative test with an experiment-wise error rate and provides high confidence with regard to any significant results obtained.

CHAPTER IV

RESULTS AND DISCUSSION

Analysis of the data is presented in the following subsections: subject data, maximum concentric, eccentric and isometric strength; prediction equations; performance on concentric tests; performance on eccentric tests; and performance on isometric tests.

Subject Data and Leg Girth

Tables I, II and III present age, height, weight (initial and final), leg length (upper: greater trochanter to lateral epicondyle, lower: lateral epicondyle to lateral malleolus), and leg girth (initial and final).

Variance analyses were carried out on all variables. Table IV shows the summary table for the analysis on age. There were no significant differences between the means for ages of the 3 training groups.

Table V shows the summary table for height. There were no significant differences between the means for heights of the 3 training groups.

In Table VI the summary table of a split-plot variance analysis of initial and final weights of the 3 training groups is presented. There was a significant difference between initial and final weights summed over all groups, (147.96 lbs. initial vs. 151.61 lbs. final) but no significant differences in initial and final group means among

TABLE I

MEAN, STANDARD DEVIATION, AND RANGE OF AGE, HEIGHT, WEIGHT,
LEG LENGTH, AND LEG GIRTH OF N=10 SUBJECTS
IN CONCENTRIC TRAINING GROUP

VARIABLE	$\bar{x}$	S.D.	RANGE
Age (yrs.)	19.13	1.60	17.64 - 23.16 (5.52)
Height (ins.)	69.28	1.99	66.00 - 72.50 (6.50)
Weight (lbs.)			
initial	149.10	16.81	123.00 - 174.50 (51.50)
final	152.25	16.07	133.00 - 180.50 (47.50)
Leg Length (ins.)			
upper	15.78	1.13	14.00 - 17.50 (3.50)
lower	16.73	0.82	15.50 - 18.00 (2.50)
Leg Girth (cm.)			
initial	46.61	3.08	43.50 - 54.00 (10.50)
final	50.83	2.95	46.00 - 54.00 (8.00)

TABLE II

MEAN, STANDARD DEVIATION, AND RANGE OF AGE, HEIGHT, WEIGHT,
LEG LENGTH AND LEG GIRTH OF N=10 SUBJECTS
IN ECCENTRIC TRAINING GROUP

VARIABLE	$\bar{x}$	S.D.	RANGE
Age (yrs.)	19.12	1.84	17.88 - 24.48 (6.60)
Height (ins.)	70.00	1.70	67.75 - 72.00 (4.25)
Weight (lbs.)			
initial	150.60	12.49	127.00 - 172.50 (45.50)
final	152.75	11.57	132.00 - 172.50 (40.50)
Leg Length (ins.)			
upper	16.38	0.69	15.50 - 17.75 (2.25)
lower	16.95	0.97	15.00 - 18.25 (3.25)
Leg Girth (cm.)			
initial	47.28	2.68	43.00 - 52.00 (9.00)
final	50.55	2.44	47.00 - 54.50 (7.50)

TABLE III

MEAN, STANDARD DEVIATION, AND RANGE OF AGE, HEIGHT, WEIGHT,
LEG LENGTH AND LEG GIRTH OF N=10 SUBJECTS
IN ISOMETRIC TRAINING GROUP

VARIABLE	$\bar{x}$	S.D.	RANGE
Age (yrs.)	18.63	0.72	17.16 - 19.64 (2.48)
Height (ins.)	68.13	2.28	65.00 - 72.75 (7.75)
Weight (lbs.)			
initial	144.20	17.79	115.00 - 183.00 (68.00)
final	149.83	16.91	115.00 - 186.00 (71.00)
Leg Length (ins.)			
upper	15.45	0.97	14.00 - 17.50 (3.50)
lower	16.23	0.69	15.00 - 17.00 (2.00)
Leg Girth (cm.)			
initial	48.75	4.03	42.50 - 58.00 (15.50)
final	49.95	3.10	46.50 - 58.00 (11.50)

TABLE IV
ANALYSIS OF VARIANCE SUMMARY TABLE FOR AGE

SOURCE OF VARIATION	SS	df	MS	F
Between Training Groups	1.6013	2	0.8006	0.3351
Within Training Groups	64.4995	27	2.3888	
TOTAL	66.1008	29		

F of 3.35 needed for significance at .05 level
with 2 and 27 d.f.

TABLE V
ANALYSIS OF VARIANCE SUMMARY TABLE FOR HEIGHT

SOURCE OF VARIATION	SS	df	MS	F
Between Training Groups	17.8791	2	8.9395	2.0057
Within Training Groups	120.3376	27	4.4569	
TOTAL	138.2167	29		
F of 3.35 needed for significance at .05 level with 2 and 27 d.f.				

TABLE VI

SPLIT-PLOT ANALYSIS OF VARIANCE SUMMARY TABLE
FOR INITIAL AND FINAL WEIGHTS

SOURCE OF VARIATION	SS	df	MS	F
Training Groups	240.5750	2	120.2875	0.2331
Error (a)	13,932.4740	27	516.0175	
Initial vs. Final Trials	199.2175	1	199.2175	13.5258*
Group x Trial Interaction	32.1609	2	16.0804	1.0917
Error (b)	397.6761	27	14.7287	
TOTAL	14,802.1035	59		

Note: * denotes significance at .05 level.

the various training groups.

The split-plot variance summary table for leg length is presented in Table VII. Lower leg length summed over the 3 training groups ($\bar{x} = 16.63$ in.) was significantly greater than upper leg length ($\bar{x} = 15.86$ in.), but there were no significant differences between groups either in total leg length or in upper or lower leg length (anatomical position).

The last analysis was on leg girth and the summary table for that variable is presented in Table VIII. As can be seen, there was not only a significant difference between initial and final leg girth summed over the 3 training groups (47.54 cm. initial vs. 50.44 cm. final), but a significant group x trial interaction. Figure 5 presents this graphically.

Sheffe's test on treatment means was applied to the results of the interaction and it was seen that the 3 training group means did not differ significantly in either the initial or final tests. Both the concentric and eccentric training groups increased significantly in leg girth over the time of the experiment while the isometric group did not increase significantly in leg girth.

Maximum Concentric, Eccentric and Isometric Strength

Table IX presents maximum concentric, eccentric and isometric strengths of N=30 subjects at Test 1. The same results are presented graphically in Figure 6, however it should be noted that in both the table and graph values for

TABLE VII
 SPLIT-PLOT ANALYSIS OF VARIANCE SUMMARY TABLE
 FOR UPPER AND LOWER LEG LENGTH

SOURCE OF VARIATION	SS	df	MS	F
Training Groups	6.810	2	3.405	2.3163
Error (a)	39.690	27	1.470	
Anatomical Position: Upper vs. Lower Leg Length	8.810	1	8.810	29.8644*
Groups x Anatomical Position	0.355	2	0.178	0.6016
Error (b)	7.965	27	0.295	
TOTAL	63.63	59		

Note: * denotes significance at .05 level.

TABLE VIII

SPLIT-PLOT ANALYSIS OF VARIANCE SUMMARY TABLE
FOR INITIAL AND FINAL LEG GIRTH

SOURCE OF VARIATION	SS	df	MS	F
Training Groups	4.1863	2	2.0931	0.1101
Error (a)	513.2081	27	19.0077	
Initial vs. Final Leg Girth	125.7443	1	125.7443	58.2176*
Group x Trial Interaction	23.7746	2	11.8873	5.5036*
Error (b)	58.3176	27	2.1599	
TOTAL	725.2309	59		

Note: * denotes significance at .05 level.

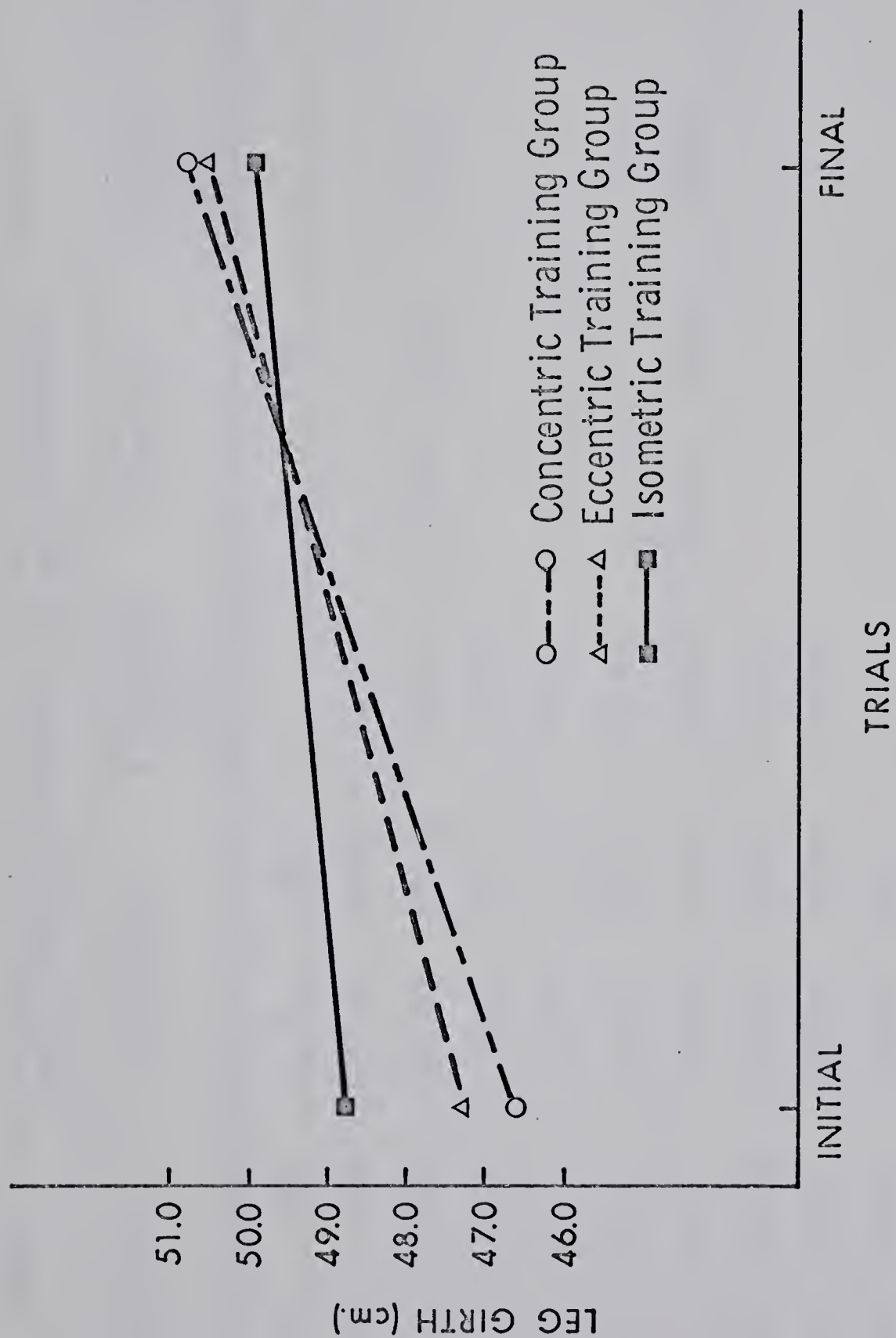


FIGURE 5: TRAINING GROUP X TRIAL INTERACTION ON LEG GIRTH

TABLE IX

MEANS AND STANDARD DEVIATIONS OF MAXIMUM CONCENTRIC, ECCENTRIC
AND ISOMETRIC STRENGTH OF N=30 SUBJECTS

ANGLE	CONCENTRIC		ECCENTRIC		ECCENTRIC % GREATER THAN CONCENTRIC		ISOMETRIC % GREATER THAN CONCENTRIC		ISOMETRIC % GREATER THAN ECCENTRIC	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
60	114.00	0.00	127.78	60.82	12.08					
70	81.71	22.80	160.09	53.89	95.92		174.57	55.17	113.64	9.04
80	105.37	29.08	180.73	55.40	71.51					
90	120.70	36.00	233.00	72.14	93.04					
100	144.10	47.55	291.97	89.03	102.61					
110	173.23	51.24	372.67	97.65	115.13		310.20	66.93	79.06	20.13
120	208.57	53.38	467.83	125.34	124.30					
130	257.57	58.97	538.47	124.18	109.05					
140	310.00	68.28	561.43	150.93	81.10					
150	345.17	71.21	572.83	224.34	65.95		633.63	214.22	83.57	10.61
$\bar{x}$	186.04		350.68		87.07		372.80		92.09	- 0.16

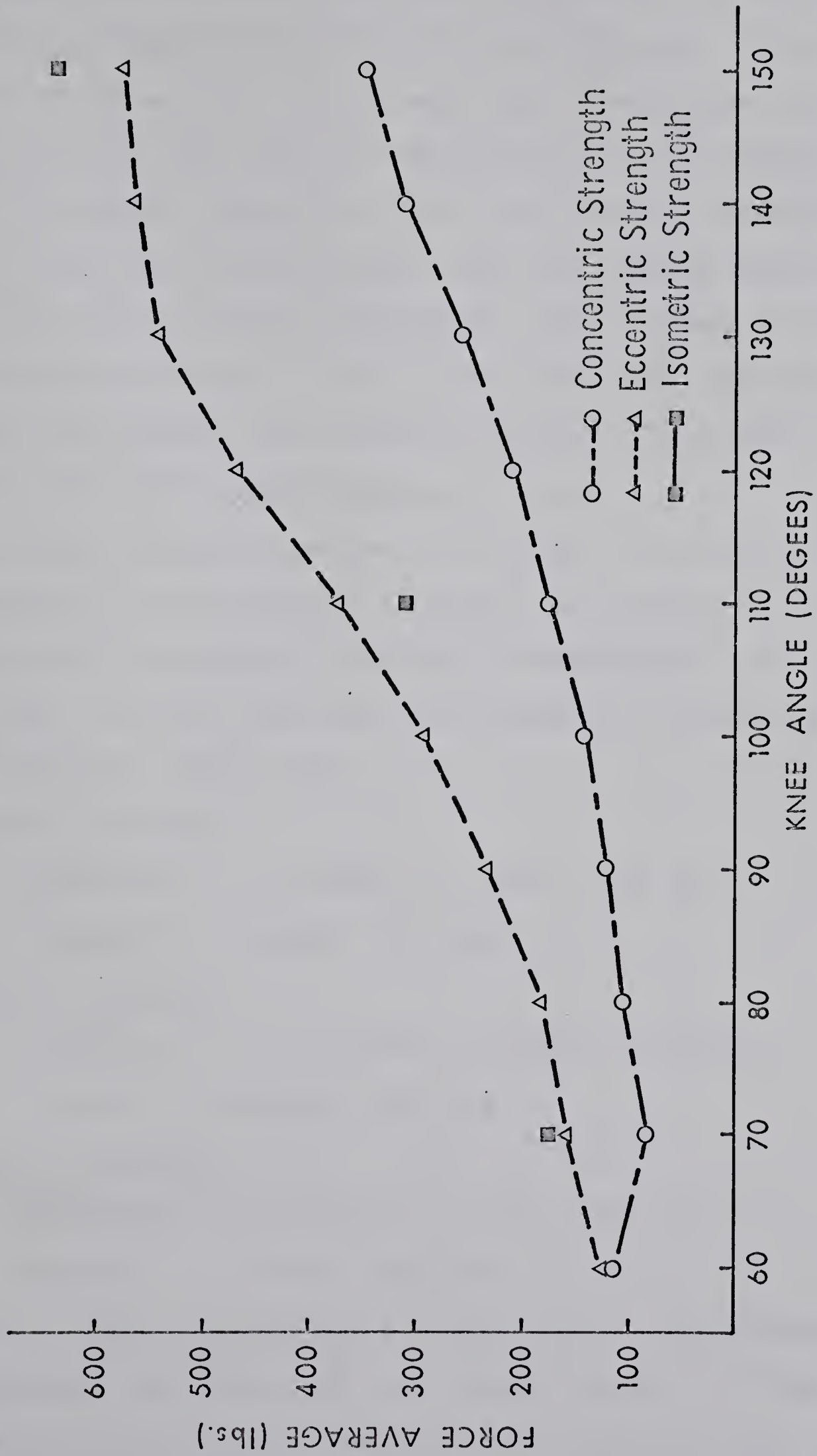


FIGURE 6; CONCENTRIC, ECCENTRIC AND ISOMETRIC STRENGTHS OF LEG EXTENSORS OF
N = 30 SUBJECTS

concentric and eccentric strength, angles 60, 70, and 150 degrees are based on less than 30 observations. At the bottom of Table IX it can be seen that the average eccentric force over the full range of movement was 87.07% greater than the average concentric force and that the average isometric force was 92.09% greater than the average concentric force over the 3 angles considered. With respect to eccentric and isometric forces, it can be seen that over the angles 70, 110 and 150 degrees, the average eccentric force was 0.16% greater than the average isometric force.

Using forces at angles 80 through 140 degrees inclusive in concentric and eccentric strength, and angles 70, 110 and 150 degrees for isometric strength, coefficients for quadratic and linear fits of lines were calculated by the method of least squares. These are:

Concentric Strength,

$$\text{Quadratic: } Y = 0.039X^2 - 5.135X + 268.398$$

$$\text{Linear: } Y = 3.400X - 185.535$$

Eccentric Strength,

$$\text{Quadratic: } Y = -0.007X^2 + 8.440X - 462.271$$

$$\text{Linear: } Y = 6.889X - 379.768$$

Isometric Strength,

$$\text{Quadratic: } Y = 0.059X^2 - 7.173X + 389.102$$

$$\text{Linear: } Y = 5.738X - 258.417$$

where y = force average and X = knee angle. The advantage of the quadratic function over the linear function in describing the relationship between average force and knee angle was

tested by variance analysis. The F value for quadratic function advantage in concentric strength was 14.52, it was 0.11 for eccentric strength and 9.57 for isometric strength. The F values for concentric and isometric strength were significant at the .05 level and the F value for eccentric strength was non-significant. The non-linear function then, provides the best fit for the relationship between knee angle and average force measured concentrically and isometrically. Force measured eccentrically may be described equally well with a linear function.

Prediction Equations

In order to determine whether mechanisms involved in concentric, eccentric and isometric strength are similar, prediction equations were formulated on concentric and eccentric strength between the angles of 80 degrees and 140 degrees inclusive; and concentric, eccentric and isometric strength at the knee angle of 110 degrees. The prediction equations along with the correlation coefficient and common variances for the various knee angles are presented in Table X, Table XI and Table XII.

The final column in Table X shows what per cent of the variance in eccentric strength is in common with the variance in concentric strength. The same column in Table XI and Table XII provides the same information on concentric and isometric strengths as well as eccentric and isometric

TABLE X

PREDICTION EQUATIONS, r , AND $r^2 \times 100$ FOR CONCENTRIC
AND ECCENTRIC STRENGTHS AT KNEE ANGLES
OF 80 TO 140 DEGREES

KNEE ANGLE	TO PREDICT		TO PREDICT		r	$r^2 \times 100$ (common variance)
	ECCENTRIC FROM CONCENTRIC		CONCENTRIC FROM ECCENTRIC			
80	Y= .8310X + 96.1069		Y= .2345X + 62.2968		.4413	19.47
90	Y= .8860X +132.2931		Y= .1961X + 73.7863		.4167	17.36
100	Y= .6697X +197.7295		Y= .1794X + 91.3145		.3465	12.00
110	Y= .7256X +252.7865		Y= .1686X +109.4238		.3497	12.22
120	Y=1.0450X +252.2811		Y= .1795X +124.1597		.4330	18.74
130	Y= .8990X +305.6475		Y= .2070X +146.3662		.4312	18.59
140	Y= .6581X +353.3890		Y= .1360X +234.1936		.2991	8.94

TABLE XI

PREDICTION EQUATIONS, r , AND $r^2 \times 100$ FOR CONCENTRIC
AND ISOMETRIC STRENGTHS AT A KNEE ANGLE
OF 110 DEGREES

KNEE ANGLE	TO PREDICT		r	$r^2 \times 100$ (common variance)
	ISOMETRIC FROM CONCENTRIC	CONCENTRIC FROM ISOMETRIC		
110	$Y = .8779X + 158.1184$	$Y = .5144X + 13.6664$	.6719	45.14

TABLE XII
PREDICTION EQUATIONS, r AND $r^2 \times 100$ FOR ECCENTRIC
AND ISOMETRIC STRENGTHS AT A KNEE ANGLE
OF 110 DEGREES

KNEE ANGLE	TO PREDICT		r	$r^2 \times 100$ (Common variance)
	ISOMETRIC FROM ECCENTRIC	ECCENTRIC FROM ISOMETRIC		
110	$Y = .2940X + 198.9308$	$Y = .7412X + 148.5464$	.4667	21.78

strengths. It appears that the concentric and eccentric strengths, as well as the eccentric and isometric strengths, have very little common variance (15.33% and 21.78% respectively). They are significantly related as indicated by the values of r ; however, prediction from one concentric or isometric strength to eccentric, and vice versa, would not be accurate. On the other hand, concentric and isometric strengths at 110 degrees do have more common variance (45.14%) and prediction between these two would be possible.

Concentric Analysis

As was mentioned in Chapter III, analyses of variance on concentric and eccentric strengths were conducted on forces measured at knee angles of 80 to 140 degrees inclusive. The summary table for the concentric test performance of the 3 training groups over the 4 test periods is presented in Table XIII.

The F value for the test period main effect approached significance (2.86 vs. 2.93), but was not significant at the .05 level. Average mean concentric forces for the 4 tests were:

Test 1: 188.51 lbs.

Test 2: 200.67 lbs.

Test 3: 235.77 lbs.

Test 4: 230.61 lbs.

Figure 7 shows the relationship graphically.

TABLE XIII

SPLIT-PLOT ANALYSIS OF VARIANCE SUMMARY TABLE
FOR CONCENTRIC TESTS

SOURCE OF VARIATION	SS	df	MS	F
Training Group	28,486.250	2	14,243.12	0.3689
Test Period	331,270.870	3	110,423.62	2.8604
Angle	7,984,342.029	6	1,330,723.67	34.4714*
Error (a)	1,119,506.950	29	38,603.69	
Training Group x Test	139,751.884	6	23,291.98	8.9096*
Training Group x Angle	50,511.850	12	4,209.32	1.6101
Test x Angle	390,443.570	18	21,691.31	8.2973*
Error (b)	1,994,665.307	763	2,614.24	
TOTAL	12,038,978.710	839		

Note: * denotes significance at .05 level.

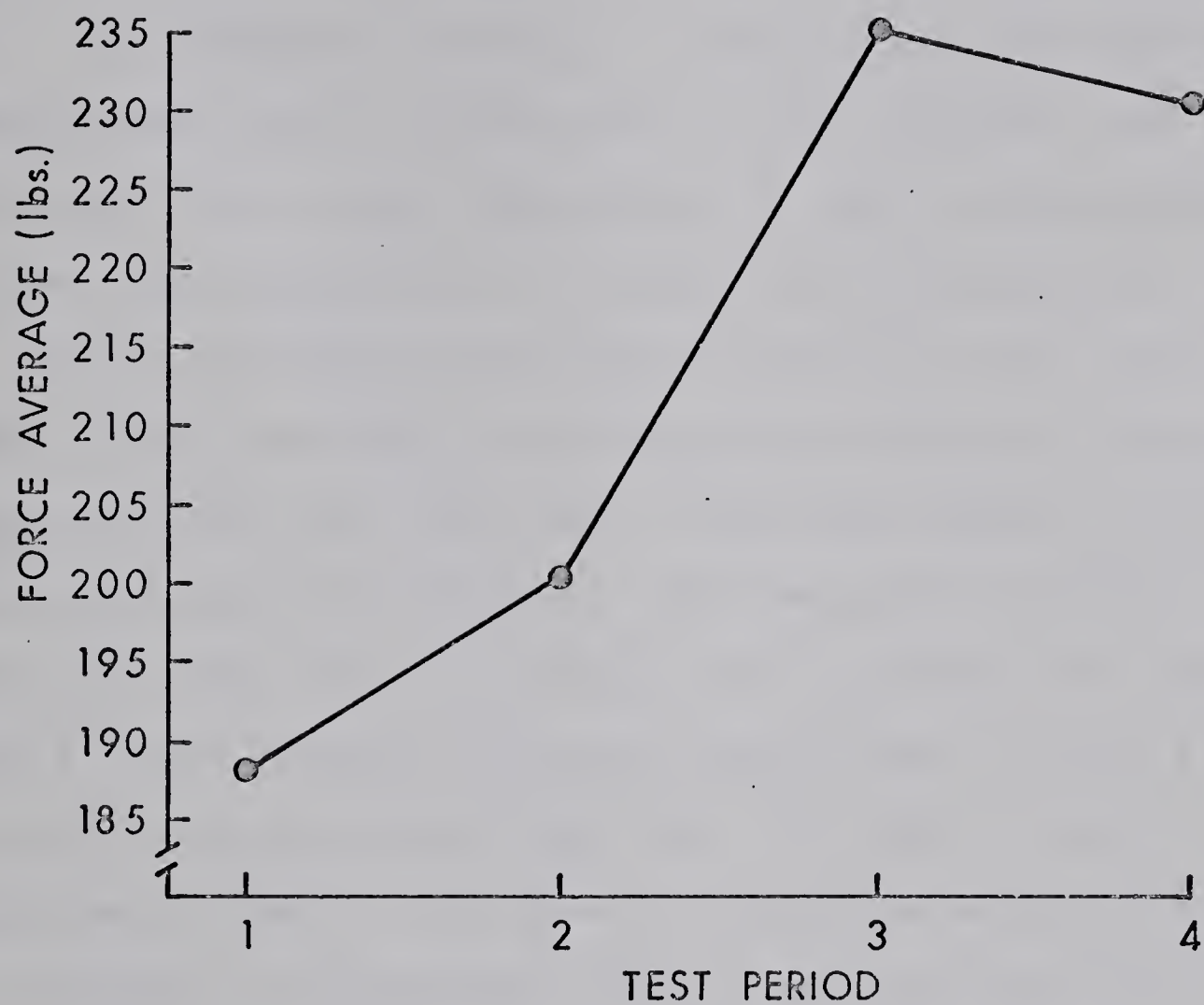


FIGURE 7: CONCENTRIC TESTS; TEST PERIOD MAIN EFFECTS.

The significant angle mean square was not unexpected. Because of the fact that the initial concentric strength is best explained by a quadratic relationship, (see p. 56), the angle main effect here summed over all tests would be expected to be significant.

Of interest, however, is the significant training group x test period interaction. This indicates that the slopes of the average performance of each training group differ. The interaction is graphically presented in Figure 8. It can be seen that the groups tend to start at the same level. The concentric training group increases slowly in strength from test 1 to test 2, and then rapidly to test 3 decreasing rapidly to test 4. The eccentric training group decreases from test 1 to test 2 and increases from test 2 to test 4. The isometric training group seems to show a negatively increasing curve from test 1 to test 3, and a slight decrease to test 4. In order to determine whether increases in strength (or decreases) for the various groups were significant, a Sheffe's test was administered. The results are reported in Table XIV.

Table XIVa indicates that the concentric training group showed a nonsignificant increase from test 1 to test 2, a significant increase from test 2 to test 3 and a significant decrease from test 3 to test 4. This result was entirely unexpected and seems to be only explainable in terms of a Type I error due to small sample size. This group did not

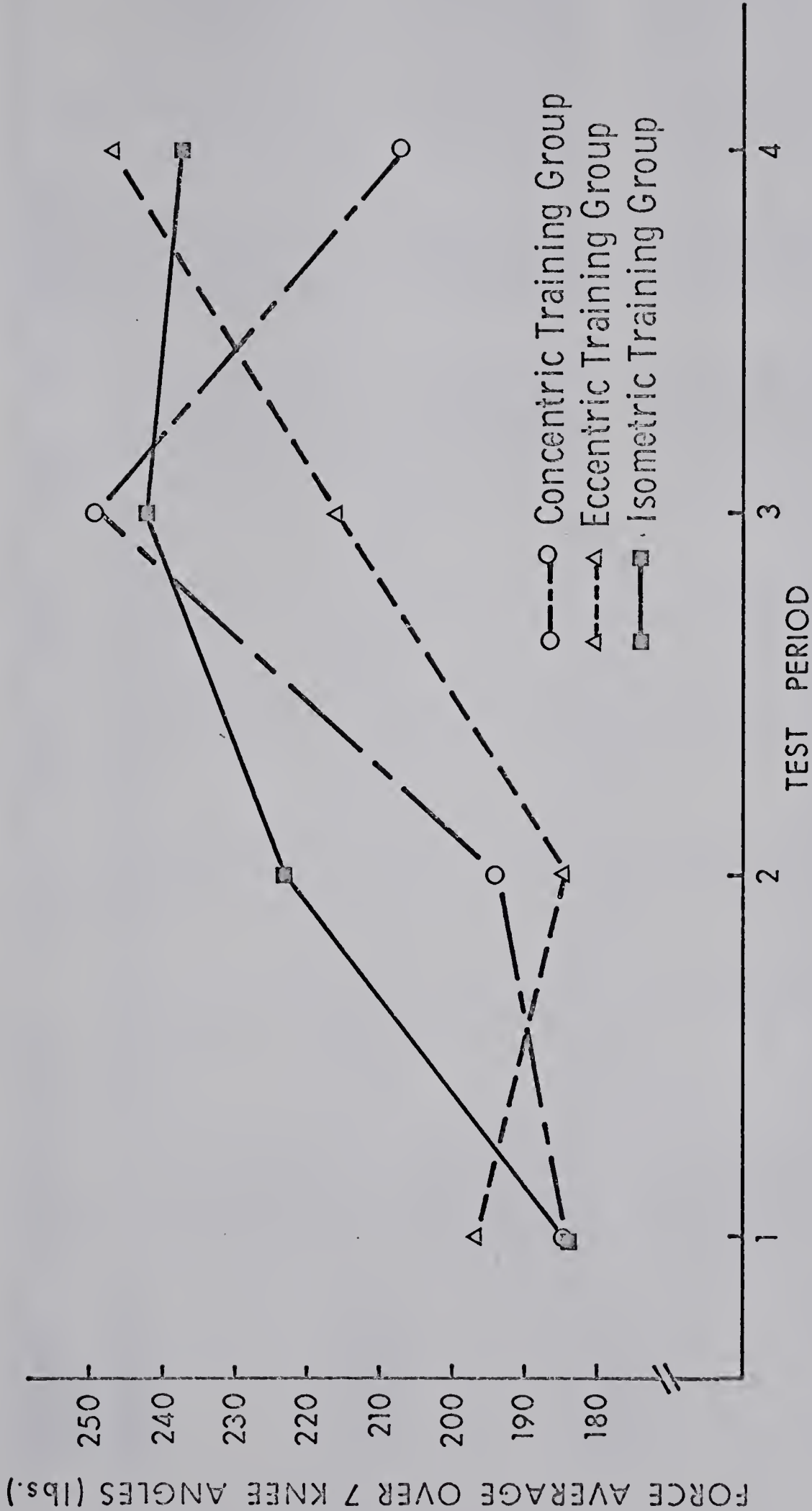


FIGURE 8: CONCENTRIC TESTS: TRAINING GROUP X TEST PERIOD INTERACTION

TABLE XIVA
SHEFFE'S TEST ON CONCENTRIC ANALYSIS TRAINING
GROUP x TEST PERIOD INTERACTION

TRAINING GROUP	COMPAR-ISON	TEST 1	TEST 2	TEST 3	TEST 4	SUM ai ²	di	PERCENT DIFFER-ENCE	sdi	t
CONCENTRIC	1 vs 2	183.89	193.69	249.04	206.87	2	9.80	5.32	8.64	1.1339
	1 vs 3	-1	0	1	0	2	65.15	35.42	8.64	7.5384*
	1 vs 4	-1	0	0	1	2	22.90	12.45	8.64	2.6589
	2 vs 3	0	-1	1	0	2	55.36	28.58	8.64	6.4056*
	2 vs 4	0	-1	0	1	2	13.18	6.80	8.64	1.5250
	3 vs 4	0	0	1	-1	2	42.17	20.38	8.64	4.8794*
ECCENTRIC	1 vs 2	197.13	184.99	216.26	247.04	2	12.14	6.56	8.64	1.4047
	1 vs 3	-1	0	1	0	2	19.13	9.70	8.64	2.2135
	1 vs 4	-1	0	0	1	2	49.91	25.31	8.64	5.7750*
	2 vs 3	0	-1	1	0	2	31.27	16.90	8.64	3.6182*
	2 vs 4	0	-1	0	1	2	62.05	33.54	8.64	7.1797*
	3 vs 4	0	0	-1	1	2	30.78	14.23	8.64	3.5615*
ISOMETRIC	1 vs 2	184.50	223.34	242.01	237.91	2	38.84	21.05	8.64	4.4941*
	1 vs 3	-1	0	1	0	2	57.51	31.17	8.64	6.6544*
	1 vs 4	-1	0	0	1	2	53.41	28.94	8.64	6.1799*
	2 vs 3	0	-1	1	0	2	18.67	8.35	8.64	2.1602
	2 vs 4	0	-1	0	1	2	14.57	6.52	8.64	1.6858
	3 vs 4	0	0	1	-1	2	4.10	1.72	8.64	0.4744

Note: * indicates significance at .05 level.
t must be greater than $\sqrt{(k-1) F} = \sqrt{(3)(3.02)} = 3.0099$
to be significant at the .05 level.

TABLE XIVb

SHEFFE'S TEST ON CONCENTRIC ANALYSIS TRAINING
GROUP X TEST PERIOD INTERACTION

TEST	COMPARISON	CONCENTRIC		ECCENTRIC		ISOMETRIC		SUM ai ²	di	PERCENT		t
		TRAINING GROUP		TRAINING GROUP		TRAINING GROUP				DIFFER- ENCE	Sdi	
Test 1	CTG vs ETG	183.89	197.13	184.50				2	13.24	7.19	8.64	1.5319
	CTG vs ITG	-1	1	0				2	0.61	0.33	8.64	0.0705
	ITG vs ETG	-1	0	-1				2	12.63	6.84	8.64	1.4613
Test 2	ETG vs ITG	193.69	184.99	223.34				2	38.35	20.73	8.64	4.4374*
	CTG vs ITG	0	-1	1				2	29.65	15.30	8.64	3.4307*
	ETG vs CTG	-1	0	0				2	8.70	4.70	8.64	1.0066
Test 3	ETG vs CTG	249.04	216.26	242.01				2	32.78	15.15	8.64	3.7929*
	ETG vs ITG	1	-1	0				2	25.75	11.90	8.64	2.9794*
	ITG vs CTG	0	-1	-1				2	7.03	2.90	8.64	1.0000
Test 4	CTG vs ETG	206.87	247.04	237.91				2	40.17	19.41	8.64	4.6840*
	CTG vs ITG	-1	1	0				2	31.04	15.00	8.64	3.5915*
	ITG vs ETG	-1	0	-1				2	9.13	3.83	8.64	1.0564

Note: * indicates significance at .05 level.
t must be greater than $\sqrt{F'} = \sqrt{(k-1) F} = \sqrt{2(3.02)} = 2.4576$
in order to be significant.

differ significantly from the other 2 groups at test 1 (see Table XIVb), it was significantly lower in mean strength than the isometric group at test 2, it was significantly greater in mean strength than the eccentric group at test 3 and significantly less than the eccentric group at test 4. Average mean strength increase was 5.32% from test 1 to test 2, an additional 30.10% from test 2 to test 3 and a further decrease of 22.97% from test 3 to test 4. Initial test to final test increase was only 12.45%. It appears then, that the most productive period in training was between 4 and 5 weeks.

The eccentric group showed a nonsignificant decrease in mean strength from test 1 to test 2 and significant increases from test 2 to test 3 and test 3 to test 4 (Table XIVa). At test 4 it showed significantly greater mean strength than the concentric group (Table XIVb). Average mean strength increase for this group was minus 6.56% from test 1 to test 2, a further 3.14% from test 2 to test 3, 15.61% from test 3 to test 4 and 25.31% from test 1 to test 4. The most productive session then, was between test 2 and test 4.

Finally, the isometric group increased significantly in mean strength from test 1 to test 2, nonsignificantly from test 2 to test 3 and decreased nonsignificantly from test 3 to test 4 (Table XIVa). At the termination of the experiment, after having increased significantly in mean strength from test 1 to test 4, this group was significantly greater in mean strength than the concentric group (Table XIVb). In tests 2 and 3 it was significantly greater in mean strength than the

eccentric group. Average mean strength increase was 21.05% from test 1 to test 2, a further 10.12% from test 2 to test 3, a decrease of 2.23% from test 3 to test 4 and an increase of 28.94% from test 1 to test 4. The first 5 weeks of training produced the most increase in mean strength. After that, training effect dropped off.

The final interaction in the concentric analysis which is of interest, is the significant test x angle interaction. This is shown graphically in Figure 9. From the widening of the curves as knee angle increases, one can see that training effect summed over all training groups, has a more beneficial effect on the greater knee angles than the smaller ones. It is difficult to test this effect for significance due to the confounding caused by the normal quadratic relationship between knee angle and average force. Figure 10 shows the various training groups' performance over the 4 tests. Of interest in Figure 9 is the increase between test 1 and test 2, test 2 and test 3, and the lack of increase between test 3 and test 4. Reference to test 4, Figure 10 seems to indicate that this lack of increase from test 3 to test 4 could be due almost entirely to the decrease in performance of the concentric training group.

Eccentric Analysis

The summary of the analysis of variance on the eccentric tests is presented in Table XV. The significant mean square for the test period main effect indicates that mean strength summed over all groups increased significantly over the 4 test

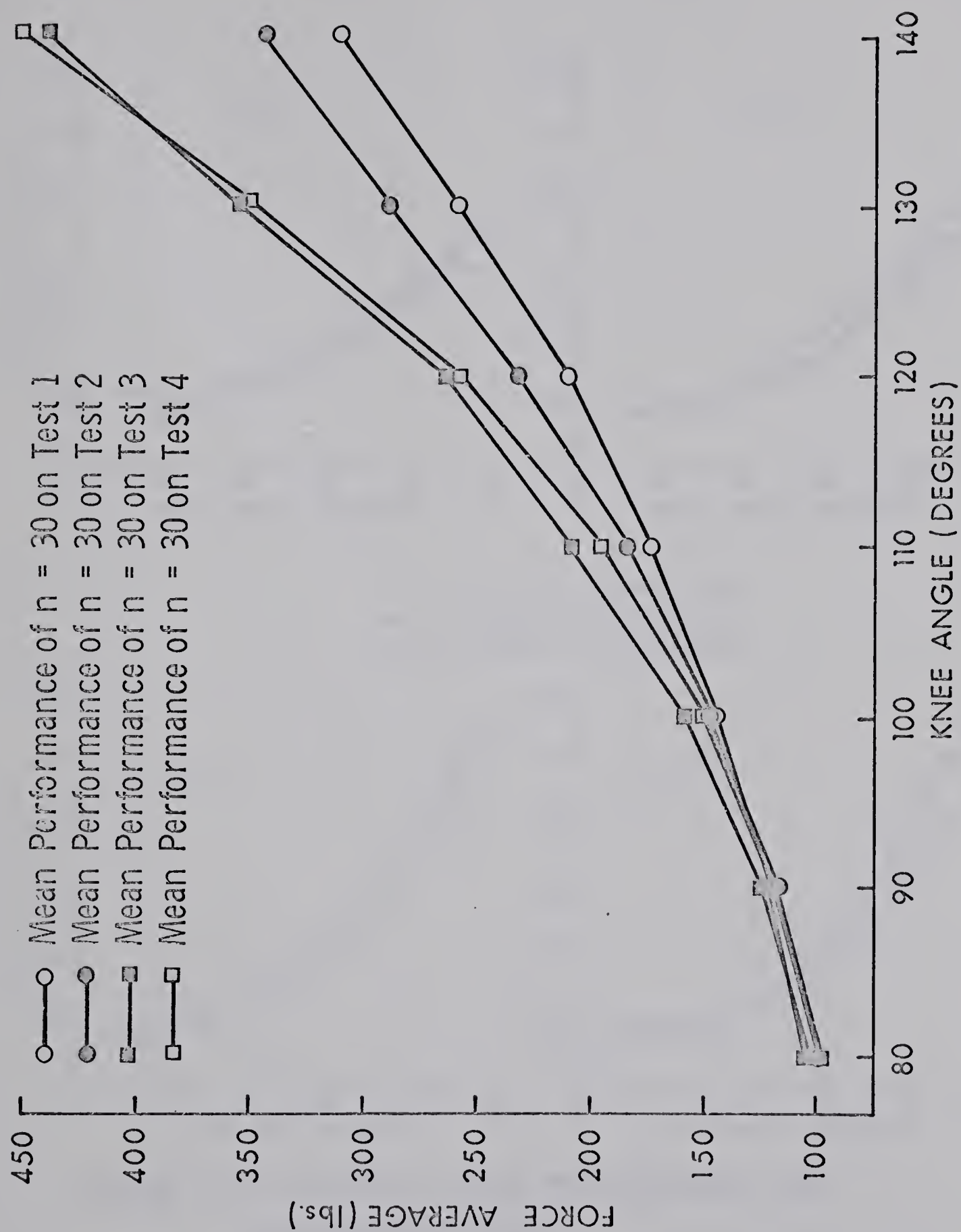


FIGURE 9: CONCENTRIC TESTS: TEST PERIOD X ANGLE INTERACTION

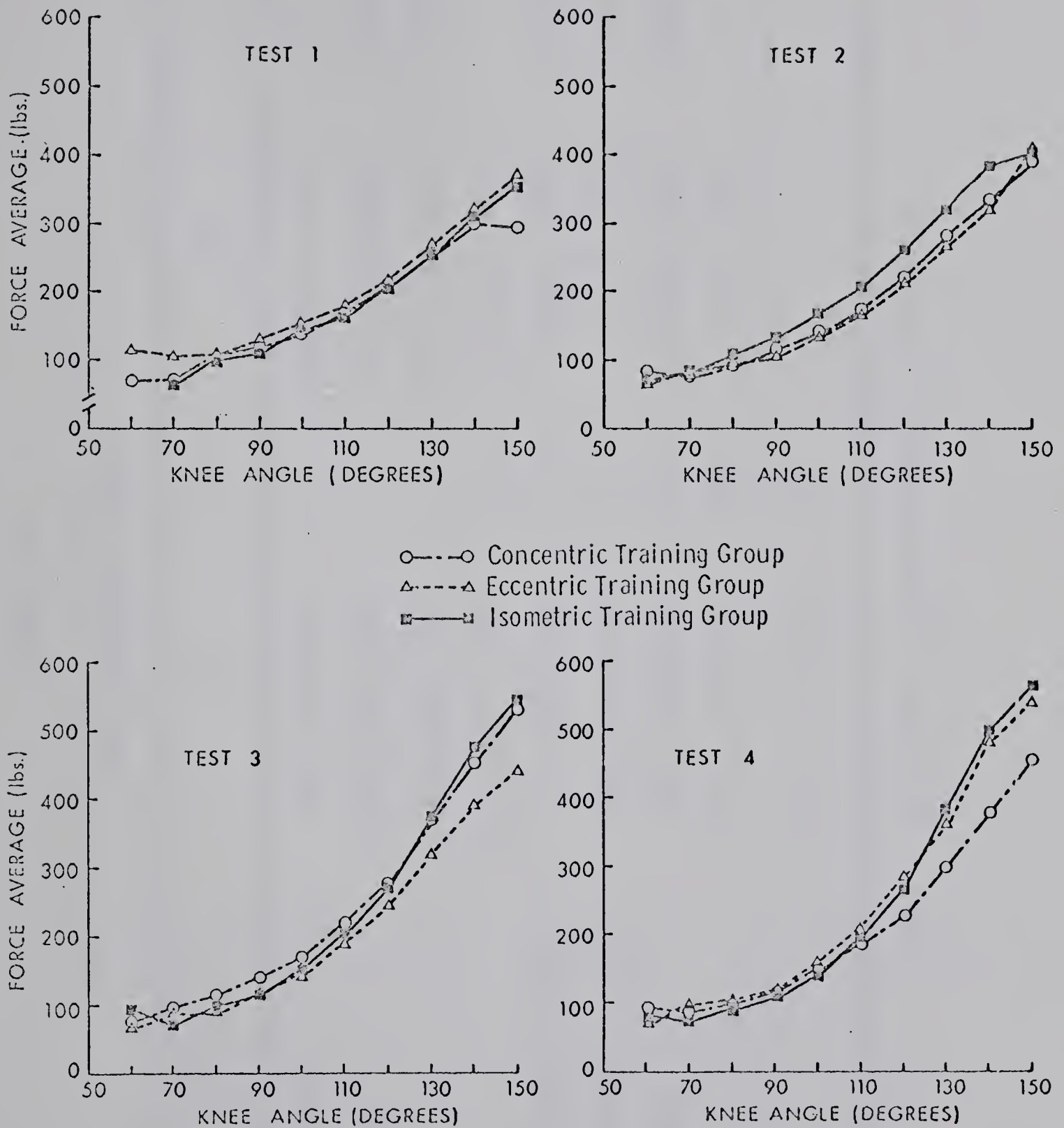


FIGURE 10: TRAINING GROUP PERFORMANCE ON CONCENTRIC TESTS.

TABLE XV

SPLIT-PLOT ANALYSIS OF VARIANCE SUMMARY TABLE
FOR ECCENTRIC TESTS

SOURCE OF VARIATION	SS	df	MS	F
Training Group	997,550.5452	2	498,775.2726	3.0770
Test Period	2,033,884.2702	3	677,961.4234	4.1824*
Angle	27,042,385.3476	6	4,507,064.2246	27.8050*
Error (a)	4,700,754.7631	29	162,094.9918	
Training Group x Test	317,350.5406	6	52,891.7567	6.4873*
Training Group x Angle	167,154.0882	12	13,929.5073	1.7084
Test x Angle	818,370.8715	18	45,465.0484	5.5700*
Error (b)	6,220,822.2296	763	8,153.1090	
TOTAL	42,298,272.6560	839		

Note: * indicates significance at .05 level.

periods. Mean eccentric strengths of the 30 subjects were:

Test 1: 378.01 lbs.

Test 2: 401.47 lbs.

Test 3: 441.33 lbs.

Test 4: 507.84 lbs.

Graphic representation is in Figure 11.

When significant group increases over the 4 tests are considered, the training group x test period interaction, is most useful. Figure 12 shows the average performance of the 3 training groups over the 4 tests. With reference to various comparisons among the means presented in Table XVI it can be seen that the concentric training group mean strength is significantly greater than that of both the eccentric and isometric groups over the first 3 tests, and remains significantly greater than that of the isometric training group in test 4. Also, the eccentric and isometric group mean strengths do not differ significantly throughout the experiment. The fact that the concentric group mean is so high at test 1 seems to be only explainable in terms of fluctuation of the type explained in concentric group performance on concentric test 4. Here, it seems reasonable to expect values for tests 2, 3 and 4 to be high simply because the mean strength on test 1 was high.

With respect to the means of the concentric group, there is a nonsignificant 6.79% increase between test 1 and test 2, a further significant increase of 18.04% between test

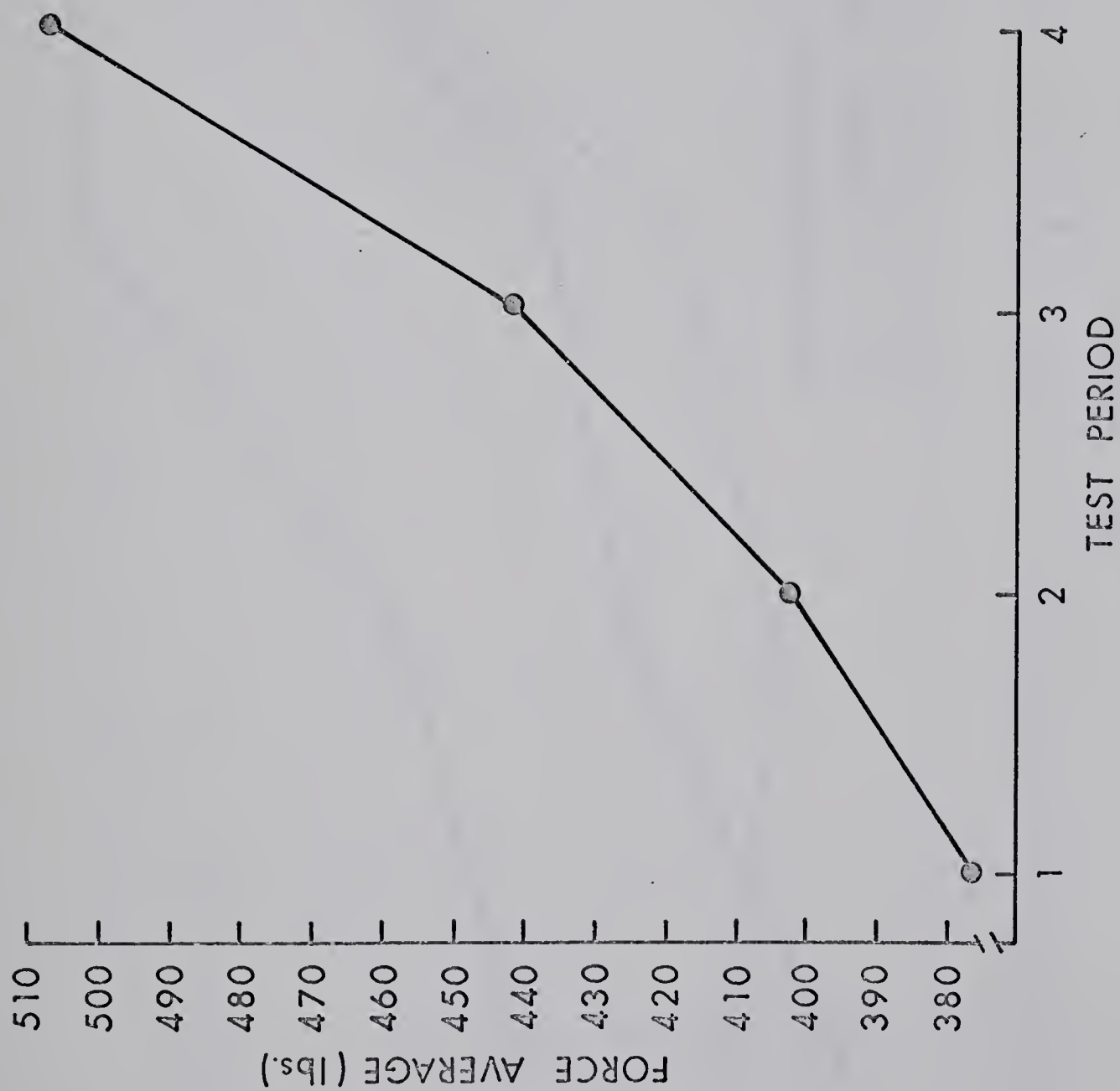


FIGURE 11: ECCENTRIC TESTS: TEST PERIOD MAIN EFFECT

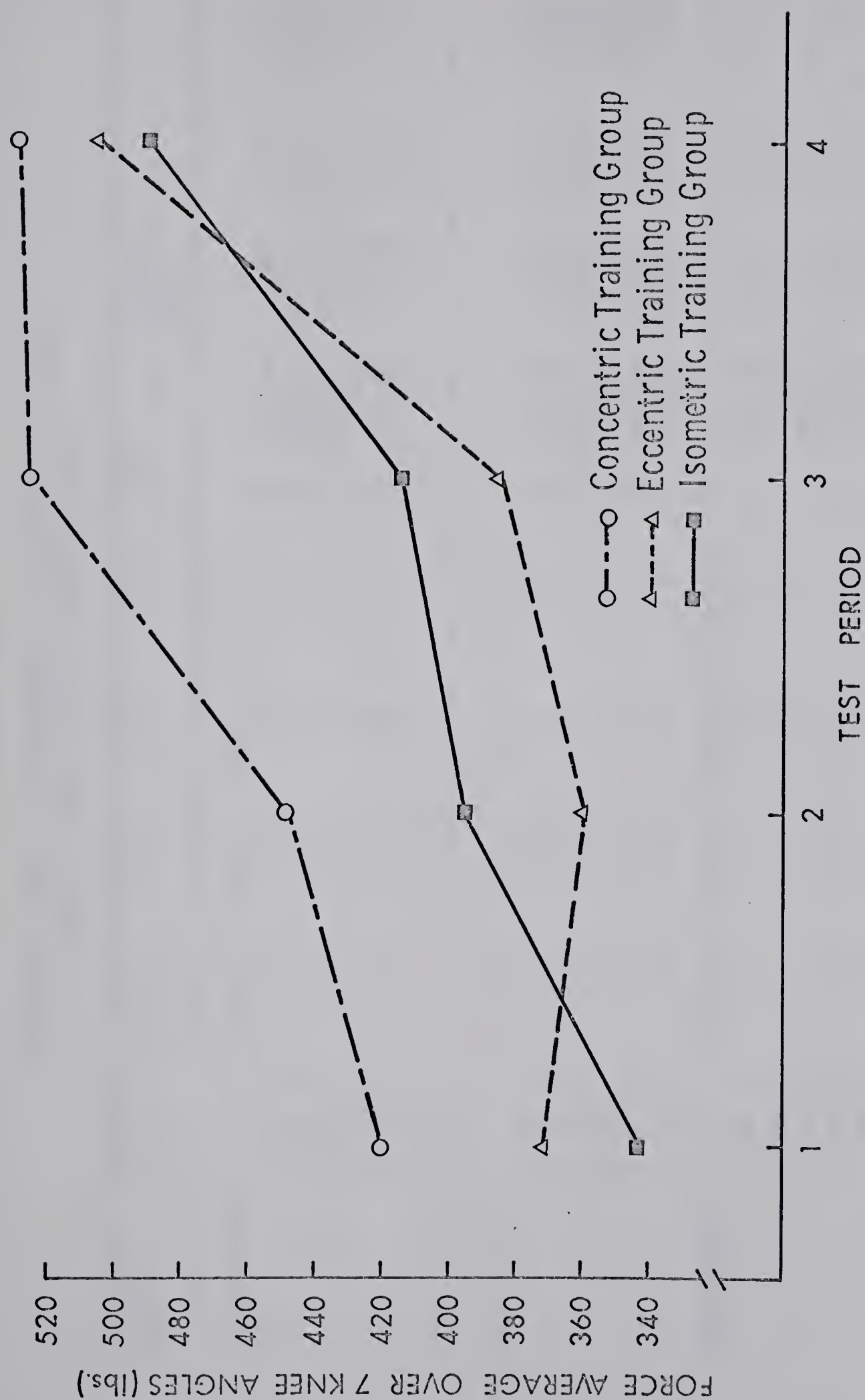


FIGURE 12: ECCENTRIC TESTS: TRAINING GROUP X TEST PERIOD INTERACTION

TABLE XVia

SHEFFE'S TEST ON ECCENTRIC ANALYSIS TRAINING
GROUP x TEST PERIOD INTERACTION

TRAINING GROUP	COMPAR- ISON	TEST 1	TEST 2	TEST 3	TEST 4	SUM ai ²	di	PERCENT DIFFER- ENCE	sdi	t
CONCENTRIC	1 vs 2	420.43	449.01	524.83	529.01	2	28.58	6.79	15.31	1.8657
	1 vs 3	-1	1	0	0	2	104.40	24.83	15.31	6.8152*
	1 vs 4	-1	0	0	1	2	108.58	25.82	15.31	7.0881*
	2 vs 3	0	-1	1	0	2	75.82	16.88	15.31	4.9495*
	2 vs 4	0	-1	0	1	2	80.00	17.81	15.31	5.2224*
	3 vs 4	0	0	-1	1	2	4.10	0.78	15.31	0.2728
ECCENTRIC	1 vs 2	371.44	360.01	385.53	504.87	2	11.43	3.17	15.31	0.7461
	1 vs 3	-1	0	1	0	2	14.09	3.79	15.31	0.9197
	1 vs 4	-1	0	0	1	2	133.43	35.92	15.31	8.7103*
	2 vs 3	0	-1	1	0	2	25.52	7.08	15.31	1.6659
	2 vs 4	0	-1	0	1	2	144.86	40.23	15.31	9.4564*
	3 vs 4	0	0	-1	1	2	119.34	30.95	15.31	7.7905*
ISOMETRIC	1 vs 2	342.17	395.37	413.64	489.63	2	53.20	15.54	15.31	3.4729*
	1 vs 3	-1	1	0	0	2	71.47	20.88	15.31	4.6655*
	1 vs 4	-1	0	0	1	2	147.46	43.09	15.31	9.6262*
	2 vs 3	0	-1	1	0	2	18.27	4.62	15.31	1.1926
	2 vs 4	0	-1	0	1	2	94.26	23.84	15.31	6.1533*
	3 vs 4	0	0	-1	1	2	75.99	18.37	15.31	4.9606*

Note: * indicates significance at the .05 level.
t must be greater than $\sqrt{F'} = \sqrt{3(3.02)} = 3.0099$
to be significant at the .05 level.

TABLE XVIb

SHEFFE'S TEST ON ECCENTRIC ANALYSIS TRAINING
GROUP x TEST PERIOD INTERACTION

TEST	COMPARISON	CONCENTRIC			ECCENTRIC			ISOMETRIC			PERCENT		
		TRAINING	GROUP	420.43	TRAINING	GROUP	371.44	TRAINING	GROUP	342.17	SUM ai ²	di	DIFFER ENCE
Test 1	ITG vs CTG	1		420.43	0		371.44	0		342.17	2	78.26	22.87
	ETG vs CTG	1			-1			-1			2	48.99	13.18
	ITG vs ETG	0			1			-1			2	29.27	8.55
Test 2	ETG vs CTG	1		449.01	-1		360.01	0		395.37	2	89.00	24.72
	ITG vs CTG	1			0			-1			2	53.64	13.56
	ETG vs ITG	0			-1			1			2	35.36	9.82
Test 3	ETG vs CTG	1		524.83	-1		385.53	0		413.64	2	139.30	36.13
	ITG vs CTG	1			0			-1			2	111.19	26.88
	ETG vs ITG	0			-1			1			2	28.11	7.29
Test 4	ITG vs CTG	1		529.01	0		504.87	-1		489.63	2	39.38	8.04
	ETG vs CTG	1			-1			0			2	24.14	4.77
	ITG vs ETG	0			1			-1			2	15.24	3.11

Note: * indicates significance at .05 level.

t must be greater than $\sqrt{F^*} = \sqrt{(k-1)(F^*(k-1,k(n-1)))} = \sqrt{2(3.02)} = 2.4576$ in order to be significant at the .05 level.

2 and test 3 and a nonsignificant increase of 0.99% between test 3 and test 4 (Table XVIa). The increase from test 1 to test 4 was significant (25.82%), the most productive training period being that between test 2 and test 3. The third to the fifth week of training then, was the most efficient.

Eccentric group mean strengths showed a nonsignificant decrease of 3.17% from test 1 to test 2, a nonsignificant increase of 0.67% from test 2 to test 3 and a significant increase of 32.13% from test 3 to test 4 (Table XVIa). Percentage increase from test 1 to test 4 was 35.92%. The most productive training period was from the sixth to eighth week.

The isometric training group showed steady progression from test 1 to test 4 (Table XVIa). Increase from test 1 to test 2 was 15.54% and was significant, it was nonsignificant from test 2 to test 3 (3.34%). Final increase of 22.21% from test 3 to test 4 was significant. Test 1 to test 4 percentage increase was 43.09%. The most productive training period here again, was the last 2 weeks of training.

As in the concentric analysis, the test period x angle interaction was significant indicating that training on the average, had a varying effect according to the knee angle concerned. It is fairly obvious from Figure 13, that the effects of training are seen more readily at a knee angle of 140 degrees vs. one of 80 degrees. Also, the fact that a linear function could predict the relationship between knee angle and average force as well as a quadratic function at test 1, can be seen graphically in the same diagram. The relationship,

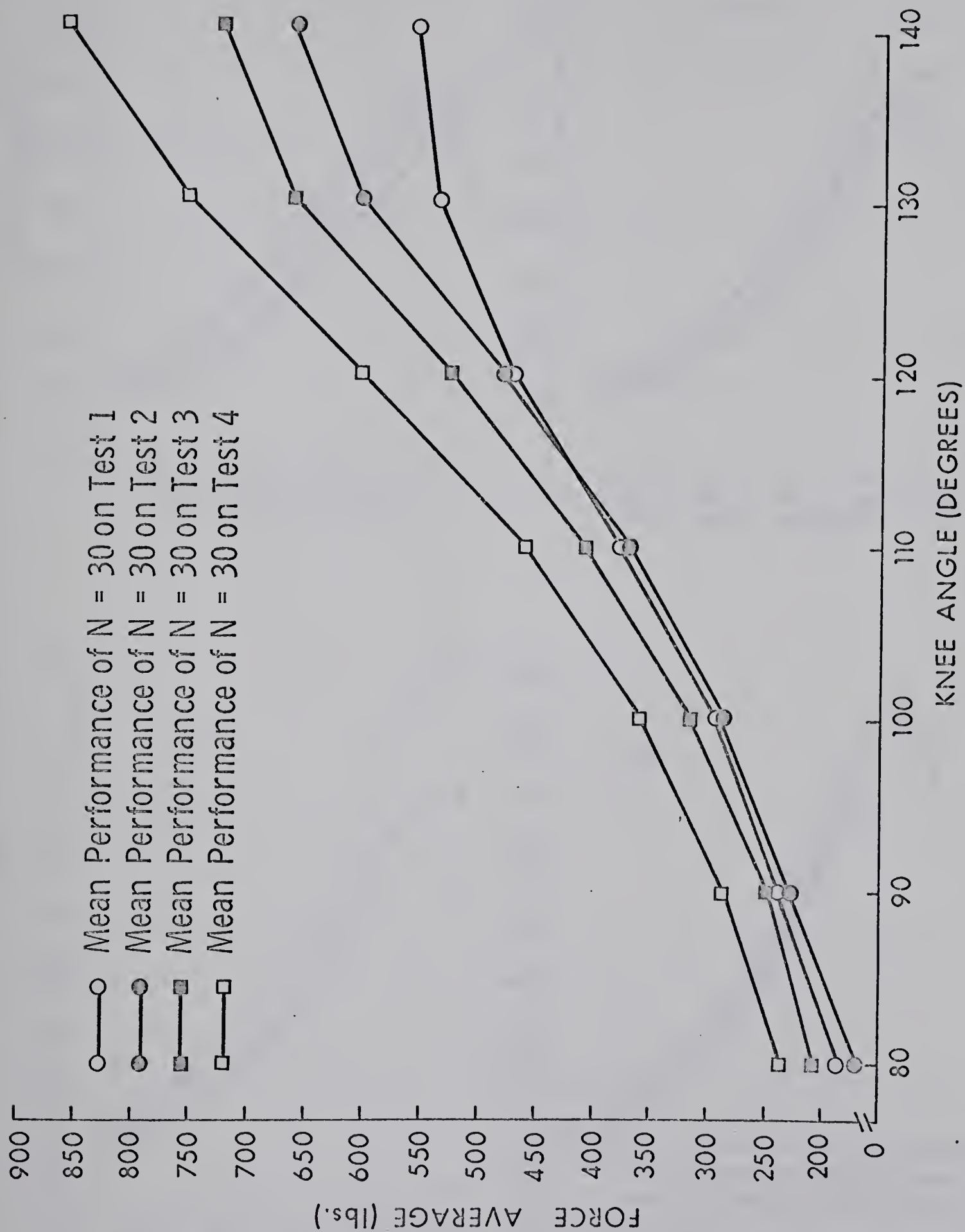


FIGURE 13: ECCENTRIC TESTS: TEST PERIOD X ANGLE INTERACTION

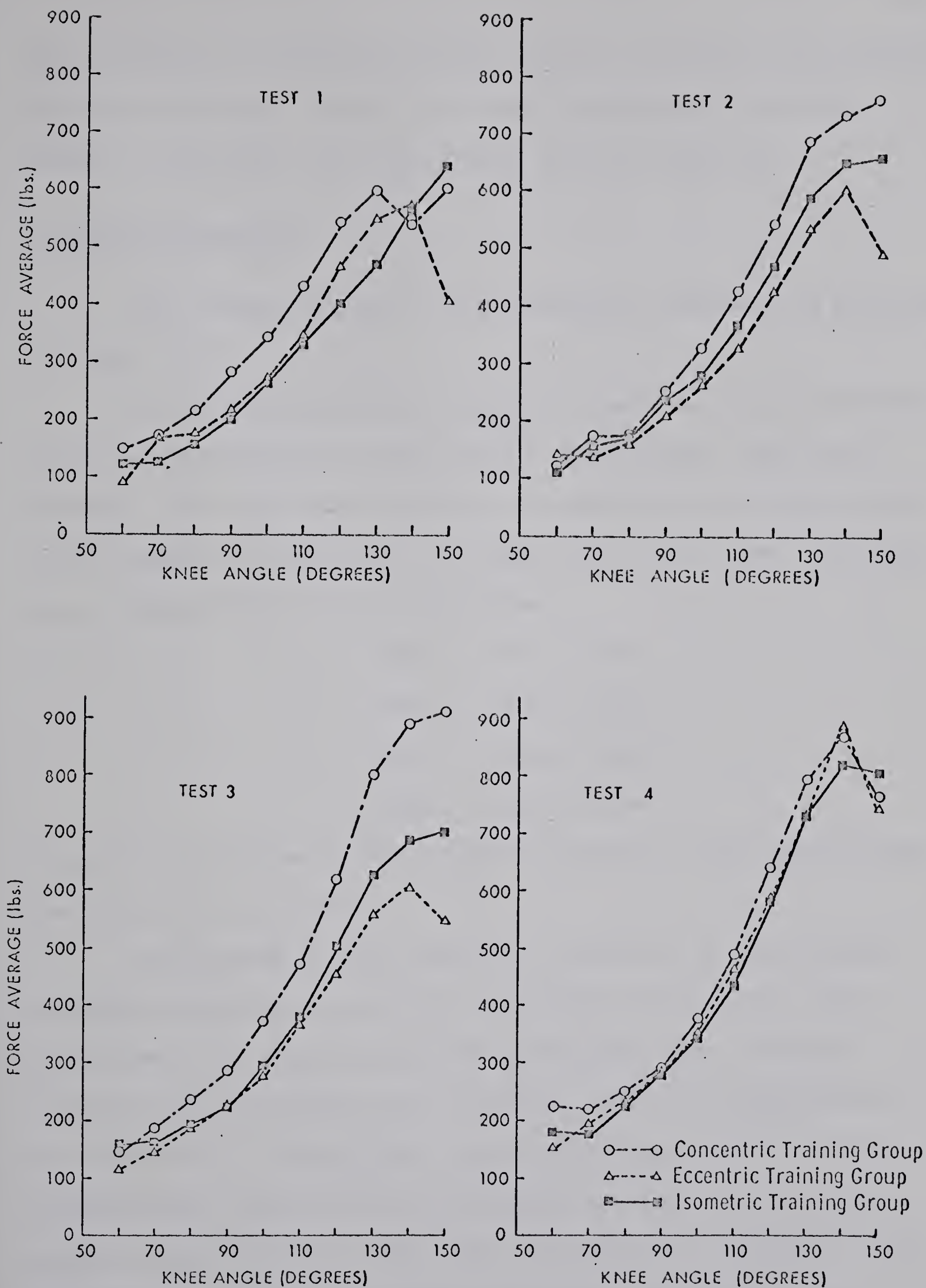


FIGURE 14: TRAINING GROUP PERFORMANCE ON ECCENTRIC TESTS.

due probably to training effect, seems to become more quadratic over the 4 tests. Figure 14 shows the various treatment groups' increases over the course of the experiment.

Isometric Analysis

The summary table of the isometric analysis is presented in Table XVII.

As in the eccentric analysis, there is seen a significant test period main effect and a significant angle main effect. The angle main effect was expected due to the quadratic nature of the curve for knee angle and force. Average mean strength for all subjects was:

Test 1: 372.80 lbs.

Test 2: 366.69 lbs.

Test 3: 391.63 lbs.

Test 4: 466.64 lbs.

Figure 15 provides graphic representation of the significant test period main effect.

Noticeable in the isometric analysis is the nonsignificant training group x test period interaction. This indicates that the form of the curves for mean strength increase for all groups are similar. This is demonstrated in Figure 16. Because the interaction mean square is nonsignificant, none of the differences in the between-groups interaction will be significant, according to Sheffe's test (21:153) (i.e. except for the obvious test period main effect). The groups, then, do not seem to differ in the rate

TABLE XVII

SPLIT-PLOT ANALYSIS OF VARIANCE SUMMARY TABLE
FOR ISOMETRIC TESTS

SOURCE OF VARIATION	SS	df	MS	F
Training Group	11,784.60	2	5,892.30	0.1250
Test Period	572,373.56	3	490,791.19	10.4198*
Angle	20,844,784.02	2	10,422,392.01	221.2738*
Error (a)	1,365,951.19	29	47,101.77	
Training Group x Test	41,333.18	6	6,888.86	0.5436
Training Group x Angle	66,947.53	4	16,736.88	1.3207
Test x Angle	909,964.43	6	151,660.74	11.9683*
Error (b)	3,890,248.27	307	12,671.82	
TOTAL	27,703,386.78	359		

Note: * indicates significance at .05 level.

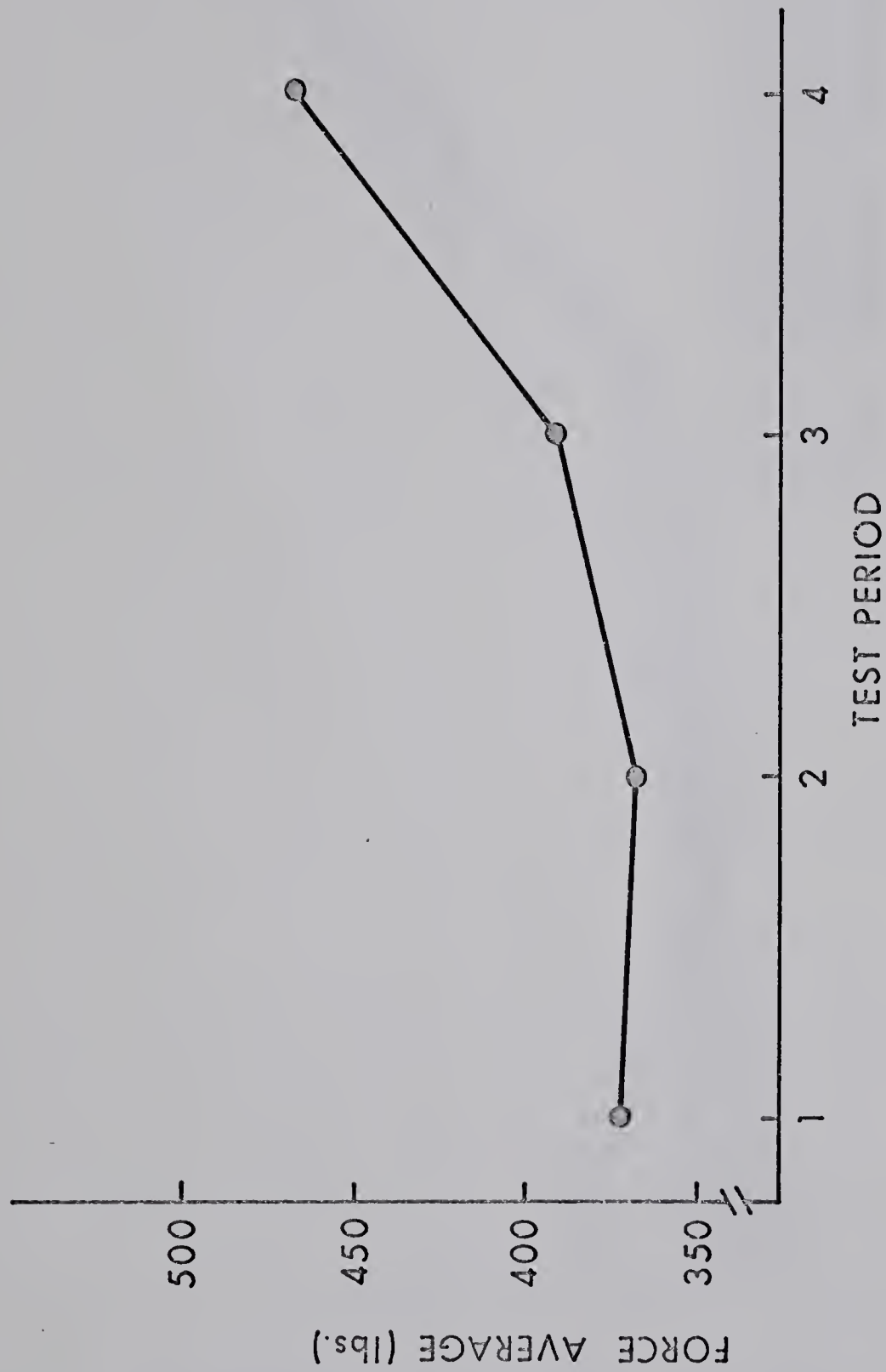


FIGURE 15: ISOMETRIC TESTS: TEST PERIOD MAIN EFFECT

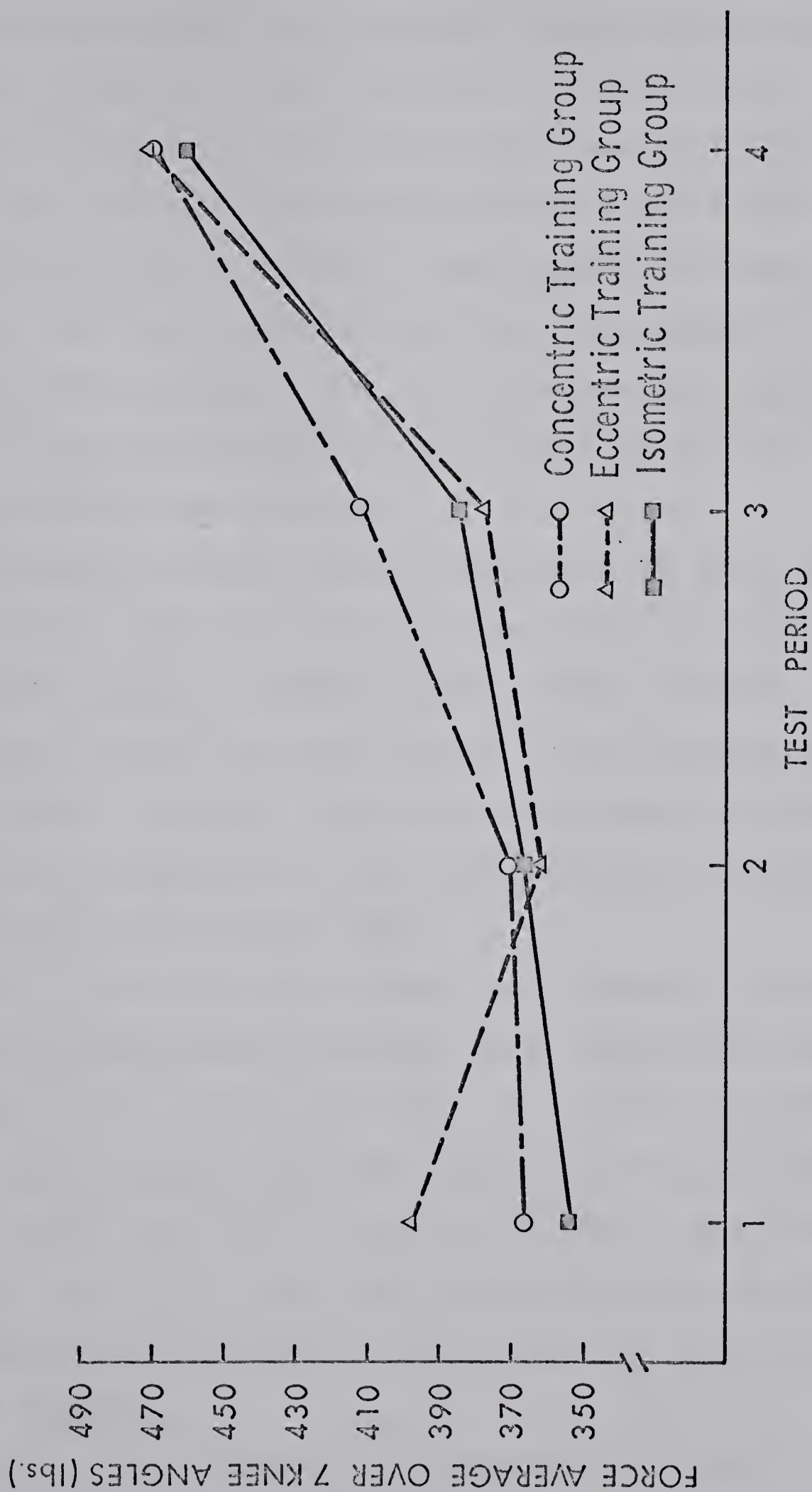


FIGURE 16: ISOMETRIC TESTS: TRAINING GROUP X TEST PERIOD INTERACTION

of mean strength increase.

In Table XVIII are presented comparisons between the increases on various tests for each treatment group. The concentric group shows significant increases only between tests 1 and 4 (27.70%) and between tests 2 and 4 (26.62%). Between tests 1 and 2 (1.08%) 2 and 3 (11.07%), and 3 and 4 (15.55%), there are no significant mean increases in average strength (Table XVIIIa). The most advantageous training period is the period between test 3 and test 4 or the sixth and seventh weeks of training.

Increases between test 2 and test 4 (8.40%), and between test 3 and test 4 (12.93%) are the only ones significant in the eccentric training group (Table XVIIIa). This is probably a result of the decrease in performance seen in test 2. Test 1 to test 4 percentage increase is 18.23%. This would seem to indicate that the most efficient training period was the sixth and seventh weeks.

As in the other two groups, the isometric training group shows significant increases only between the first and last tests, vis. 1 and 4 (30.36%), and 2 and 4 (26.59%). Non-significant increases were seen between test 1 and test 2 (3.77%), test 2 and test 3 (5.27%) and test 3 and test 4 (21.32%). As in the other two training groups, the most advantageous training period was between the fifth and seventh weeks of training.

The last significant interaction is the test x angle

TABLE XVIII
SHEFFE'S TEST ON ISOMETRIC ANALYSIS TRAINING
GROUP x TEST PERIOD INTERACTION

TRAINING GROUP	COMPAR- ISON	TEST 1	TEST 2	TEST 3	TEST 4	SUM ai ²	di	PERCENT DIFFER- ENCE	sdi	t
CONCENTRIC	1 VS 2	366.93	370.90	411.53	468.60	2	3.97	1.08	29.07	0.1365
	1 VS 3	-1	1	0	0	2	44.60	12.15	29.07	1.5344
	1 VS 4	-1	0	0	1	2	101.67	27.70	29.07	3.4979*
	2 VS 3	0	-1	1	0	2	40.63	10.95	29.07	1.3978
	2 VS 4	0	-1	0	1	2	97.70	26.34	29.07	3.3614*
	3 VS 4	0	0	-1	1	2	57.07	13.86	29.07	1.9635
ECCENTRIC	1 VS 2	398.17	362.53	378.10	470.77	2	35.64	9.83	29.07	1.2262
	1 VS 3	1	-1	0	0	2	20.07	5.30	29.07	0.6905
	1 VS 4	-1	0	0	1	2	72.60	18.23	29.07	2.4978
	2 VS 3	0	-1	1	0	2	15.57	4.29	29.07	0.5356
	2 VS 4	0	-1	0	1	2	108.24	29.85	29.07	3.7240*
	3 VS 4	0	0	-1	1	2	92.67	24.50	29.07	3.1883*
ISOMETRIC	1 VS 2	353.30	366.63	385.27	460.57	2	13.33	3.77	29.07	0.4586
	1 VS 3	-1	0	1	0	2	31.97	9.04	29.07	1.0999
	1 VS 4	-1	0	0	1	2	107.27	30.36	29.07	3.6906*
	2 VS 3	0	-1	1	0	2	18.64	5.08	29.07	0.6413
	2 VS 4	0	-1	0	1	2	93.94	25.62	29.07	3.2320*
	3 VS 4	0	0	-1	1	2	75.30	19.54	29.07	2.5907

Note: * indicates significance at .05 level.
t must be greater than $\sqrt{F'} = \sqrt{(k-1)F} = \sqrt{3(3.03)} = 3.0149$
to be significant at the .05 level.

interaction. This is shown in Figure 17. Nearly all of the training effects are seen in the 150 degree angle. The disproportionate allotment of training effects probably provides the answer as to why there was no significant training group x test interaction. All of the differences would be seen at only one angle. This is also illustrated in Figure 18.

With reference back to Table XVIIIa it should be noted that the eccentric training group did not increase significantly in mean isometric strength as did the other 2 training groups. This was probably a result of the inordinately high performance at test 1. Nevertheless, the fact that the training group x test period interaction was nonsignificant (Figure 16), indicates that the form of the eccentric training group curve did not differ significantly from the forms of the curves for the other 2 training groups. Since increases from test 1 to test 4 for these 2 groups were significant, it seems fair to conclude that the nonsignificant test 1 to test 4 increase for the eccentric training group was due to sampling error because of a small number of observations (vis. 10).

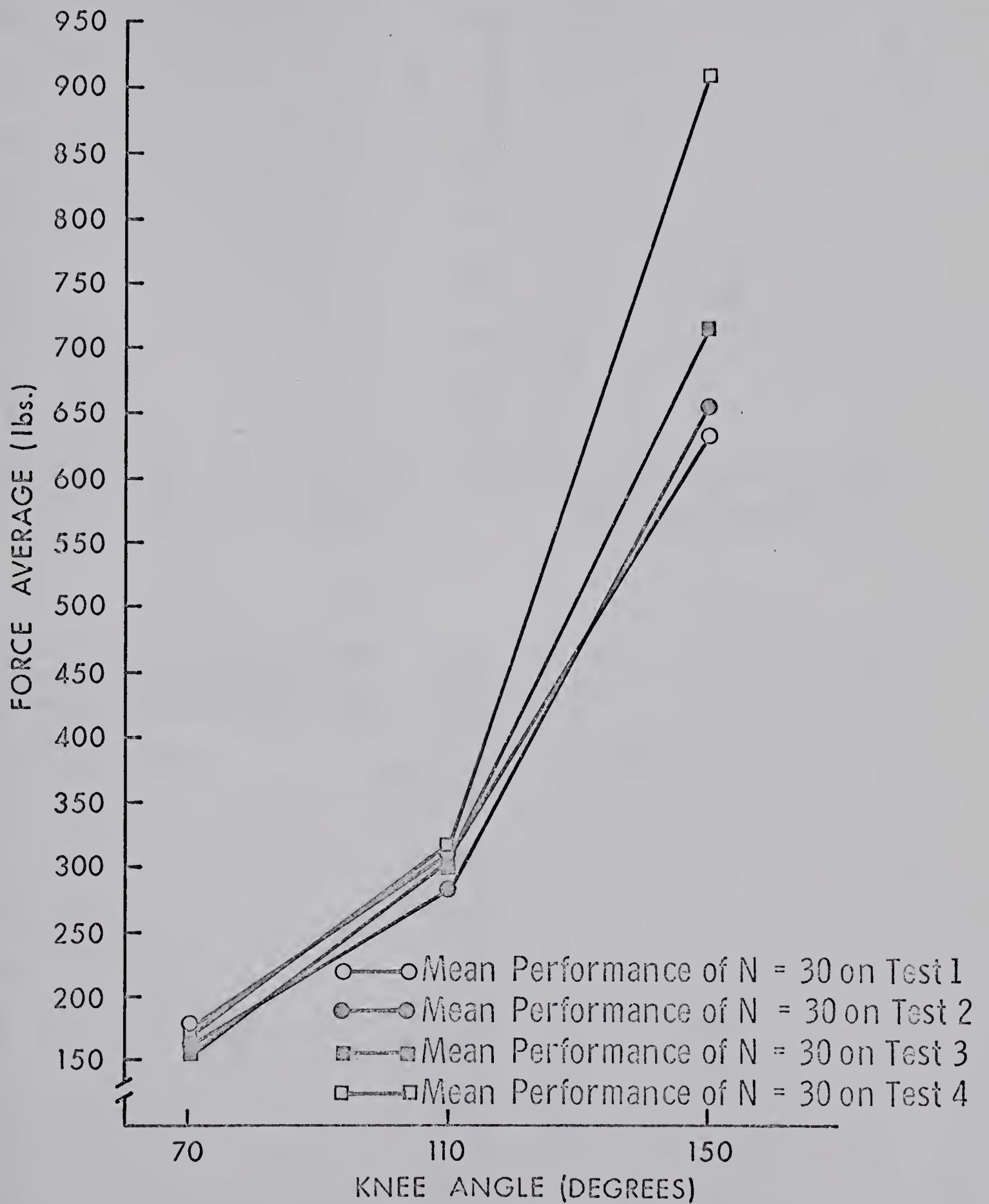


FIGURE 17: ISOMETRIC TESTS: TEST PERIOD X ANGLE INTERACTION

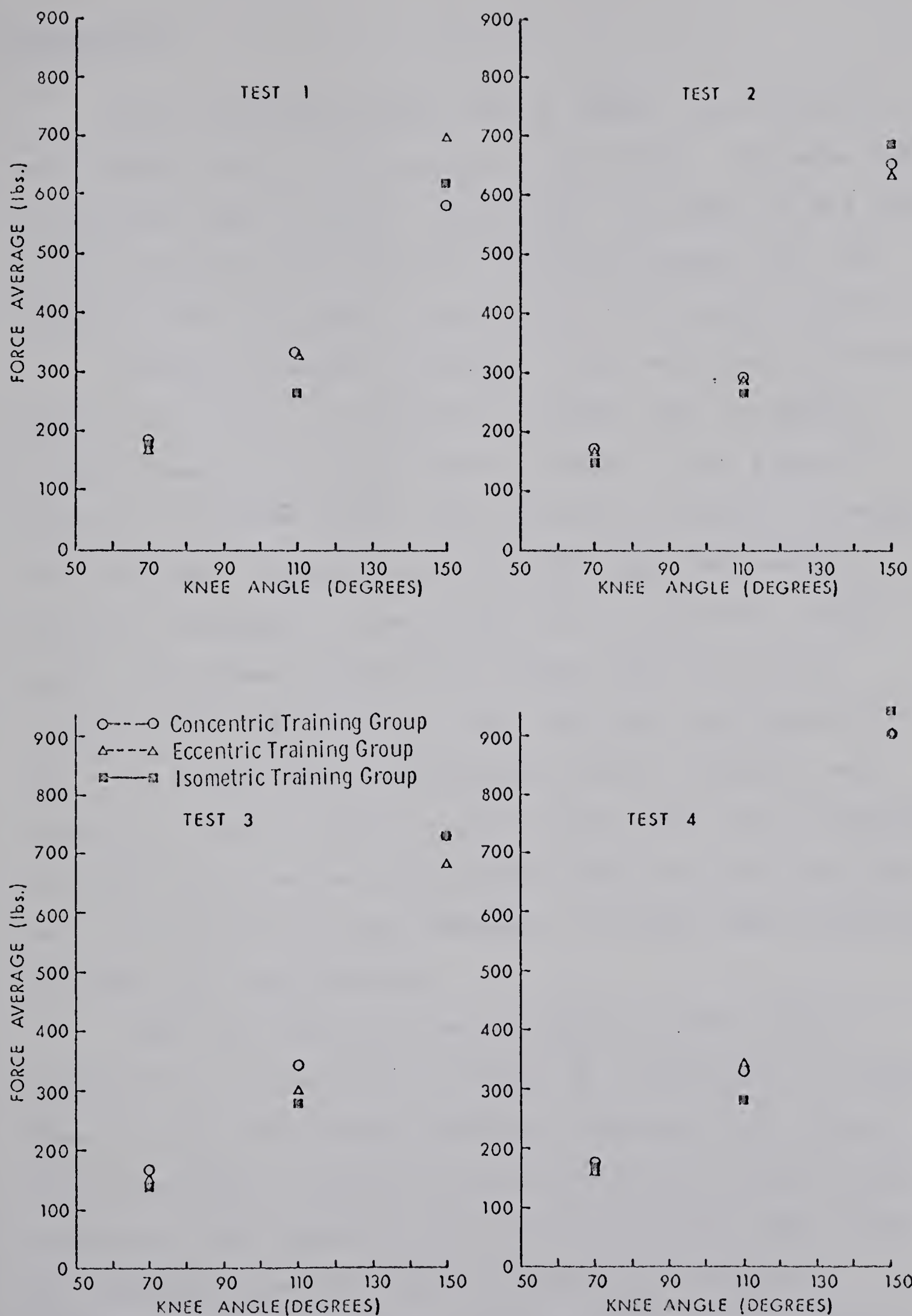


FIGURE 18: TRAINING GROUP PERFORMANCE ON ISOMETRIC TESTS.

Discussion

The 3 training groups did not differ significantly in age, height, weight, leg length or leg girth. It seems fair to conclude then, that the significant increases in leg girth of the concentric and eccentric training groups over the course of the experiment, were due to the training effect.

Average eccentric strength of leg extensors is 87.07% greater than average concentric strength over 10 angles. Average isometric strength over 3 angles in the range of movement is 92.09% greater than average concentric strength over the same 3 angles and only 0.16% less than average eccentric strength. These results are in general confirmation with those of Rasch and Pierson (52), but vary slightly with those of Doss (20), and Singh and Karpovich (60), who found larger differences between eccentric and isometric forces. However, their experiments were conducted on elbow flexor and extensor groups and the ratio may very well be different for leg extensors. Further experimentation is needed for confirmation.

Both the concentric and isometric curves can be explained more adequately in terms of a non-linear function than in terms of a linear function, linking force average with knee angle. The fact that the eccentric curve became noticeably more quadratic from test 1 to test 4 (see Figure 12) indicates that the true relationship is quadratic rather than linear and that the nonsignificant F obtained

over linear fit was due to sampling error in the first test. Once again, further experimentation will be necessary to corroborate this opinion.

An interesting question is whether or not the 3 types of forces are interrelated and operate with the same neuromuscular mechanism. Results here show that there is a very small amount of common variance between concentric and eccentric strengths over the angles of 80 to 140 degrees (15.33%), and between isometric and eccentric strengths at a knee angle of 110 degrees (21.78%). The relationship increases to 45.14% between concentric and isometric strengths at 110 degrees. From these data then it would not be possible to predict a subject's concentric or isometric strength from his eccentric strength at a given knee angle (at only 110 degrees in the case of eccentric and isometric). A fairly accurate prediction could be made between concentric and isometric strength at a knee angle of 110 degrees but it is unknown whether or not this relationship would hold over the range of movement.

In the concentric analysis there was no significant test period main effect. Results indicated that both the eccentric and isometric training groups increased significantly in mean strength over the 4 tests but that the concentric training group did not. The reason for the decrease in mean strength of the concentric training group (see Figure 8) in test 4 of the analysis is not known. Prediction of the

test 4 results from extrapolation of the first 3 test results would lead to an extremely high value for performance on test 4. Also, assuming that the concentric group mean performance is somewhere between that of the eccentric and isometric group, means that the former's performance is dependent on that of the latter two. Any prediction based on this assumption would give values for the concentric group exactly on the mean of the other 2 groups. The point here is that without any other studies with which to cross-validate the results found here, nothing can be said about the decrease in performance of the concentric training group. It seems reasonable to postulate that the mean strength should increase but this cannot be investigated further at this time.

The most productive training time for subjects training concentrically is that between the fourth and fifth weeks of training. The eccentric training group shows most percentage increase from test 2 to test 4 (i.e. the fourth to the seventh week of training). The isometric group's most productive period of training is the period between test 1 and test 2. The isometric training regimen provides the most advantageous training effect for short periods of training of 2 to 3 weeks. With another 2 weeks of training, both isometric and concentric training regimens are most advantageous in producing strength, and over 7 weeks of training either the eccentric or isometric training regimens are better than the concentric. It would seem that because the isometric group is significantly greater

in mean strength that the eccentric group over the first 3 tests, that this training regimen would be a better one for developing concentric strength over periods of training of 5 weeks or less. Over a period of 7 weeks the mean strengths of the 2 training groups do not differ significantly and it must be concluded that the 2 methods are equally effective. Conclusions about concentric training at this time must be tentative, but on the assumption that strength would normally be expected to increase from test 3 to test 4, it would seem that concentric training would be expected to be at least as effective as the other 2 in increasing concentric strength after 7 weeks of training.

There is seen in the eccentric analysis a significant test period main effect, summed over training groups and knee angles. This is equivalent to saying that subjects, on the whole, increased significantly in mean eccentric strength over the course of the experiment. The training groups differed with respect to their mean strength increases as indicated in Figure 12. A problem arises here in that the mean strength for the concentric training group is significantly greater than the other 2 over the first 3 tests, and remains significantly greater than the mean strength for the isometric training group over test 4. However, if this initial difference is accepted as due to sampling error, the slopes for the concentric and isometric groups being similar, indicate that these two types of training would provide faster rates of

strength increase than eccentric training. The most productive period for the concentric training group was the period between test 2 and test 3 (i.e. training week 4 and training week 5). The most productive period for the eccentric training group was the period between test 3 and test 4 and that of the isometric training group was the same with nearly as great an increase between test 1 and test 2.

The percentage increases over the 4 tests for the 3 training groups when strength is measured isometrically are as follows:

Concentric training group - $27.70\% = 3.46\%/week$

Eccentric training group - $18.23\% = 2.28\%/week$

Isometric training group - $30.36\% = 3.79\%/week$

It can be seen that all 3 training methods provide a substantial mean strength increase per week. Hettinger and Mueller (28) found increases of 5 per cent per week when training isometrically. Results for the isometric training group here are in fairly high accord with theirs. In fact, all training groups showed similar mean strength increases. This fact is corroborated by the nonsignificant training group x test period interaction. It appears that the 3 training groups are equally effective in increasing isometric strength. The most productive training period for all training regimens was that between test 3 and test 4.

A problem which must be brought up now is the problem of friction in the backboard. After the experiment was

completed, the arborite backboard was scratched where the seat belt buckle touched it. This being so, the subjects performing an eccentric contraction would have been assisted by friction and those performing a concentric contraction would have been hindered. This would affect mean scores for the 3 types of contractions and would also provide differing training stimuli for the concentric and eccentric training groups. The influence of this variable is not known at present and it requires more attention in the future.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The primary purpose of this study was to determine the relative efficacy of concentric, eccentric and isometric training of leg extensors in increasing maximum voluntary strength of leg extensors. Sub-problems were the design of equipment for measurement, establishment of concentric, eccentric and isometric forces of leg extensors and the formulation of prediction equations for predicting one type of strength from another.

Thirty-nine randomly selected subjects started the study and the final analysis was conducted on 3 groups of $N = 10$ each. Three separate analyses were conducted on the 3 types of strength respectively. The analysis was conducted on average force (to the nearest whole number) of 2 trials per subject at angles 80 through 140 degrees for the concentric and eccentric analyses, and 70, 110 and 150 degrees for the isometric analysis. The analysis itself was a split-plot analysis of variance with 2 factors between subjects and 2 factors within subjects. It was a mixed model with subjects randomly selected and assigned, and training groups, knee angles and test periods non-randomly assigned.

The following results were found:

1. Both eccentric and isometric forces of leg extensors,

although they are essentially the same, are greater than concentric force.

2. Mean leg girths of the 3 training groups did not differ significantly among each other at either the initial test or final test. However, the initial to final values of the concentric and eccentric groups did increase significantly indicating that training of a dynamic nature is associated with hypertrophy, while that of a static nature is not.
3. Concentric and eccentric forces are unrelated over 10 knee angles with regard to neuromuscular mechanisms involved. The same is true for eccentric and isometric forces for a knee angle of 110 degrees. However, concentric and isometric forces at 110 degrees are related and prediction from one to the other is possible.
4. The relationship between knee angle and strength for concentric, eccentric and isometric strength is non-linear. Also, training effects by all 3 types of contractions are seen only at greater knee angles.
5. Concentric strength increases can be more rapidly achieved through isometric training than either concentric or eccentric. However, both eccentric and isometric training are equally effective over 7 weeks of training.
6. Concentric and isometric training provide faster rates of mean eccentric strength increase than does eccentric.

7. Mean isometric strength increase can be achieved equally well through either concentric, eccentric or isometric training.

Conclusions

In conclusion, specificity of strength increases were not found in the present study. Isometric training proved to be the most effective in improving strength of all 3 types over a training period of 7 weeks.

Recommendations

Further study into this area is necessary to corroborate findings on various strengths of the extensor muscle groups of the legs. However, before this is undertaken, work should be done on the dynamometer in the form of reducing friction, noise, etc. Also, a more efficient recording system would be desirable; e.g. one in which knee angle and force could be taken off the same graph.

An interesting excursion would be the duplication of the foregoing experiment with different contraction speeds and/or contraction times. Due to the fact that there is a relationship between speed of muscular contraction and force output (31), there may be seen a different effect due to various types of training regimens.

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APPENDIX A

TRAINING AND TESTING PERIODS

Initial Test	Week 1
O_2 Test 1	Week 2
Training Session 1.....	Week 3
Training Session 2.....	Week 3
Training Session 3.....	Week 3
Training Session 4.....	Week 4
Training Session 5.....	Week 4
Training Session 6.....	Week 4
Test 2: Training Session 7.....	Week 5
Training Session 8.....	Week 5
Training Session 9.....	Week 5
O_2 Test 2: Training Session 10.....	Week 6
Training Session 11.....	Week 6
Training Session 12.....	Week 6
Test 3: Training Session 13.....	Week 7
Training Session 14.....	Week 7
Training Session 15.....	Week 7
Training Session 16.....	Week 8
Training Session 17.....	Week 8
Training Session 18.....	Week 8
O_2 Test 3.....	Week 9
Final Test.....	Week 9

APPENDIX B

ANTHROPOMETRICAL DATA

AGE, HEIGHT, WEIGHT, LEG LENGTH AND LEG GIRTH OF SUBJECTS

IN CONCENTRIC TRAINING GROUP

SUBJECT	AGE (yrs.)	HEIGHT (ins)	WEIGHT (lbs)		LEG LENGTH (ins.)		LEG GIRTH (cm.)	
			Initial	Final	Upper	Lower	Initial	Final
2	23.16	72.25	165.00	162.50	16.50	18.00	49.00	53.00
4	20.56	69.00	153.00	158.50	16.25	17.00	46.61*	51.00
5	19.72	67.25	123.00	133.00	14.50	15.75	46.00	53.00
6	18.32	68.25	156.00	161.50	15.00	16.25	49.00	53.50
7	17.88	68.50	141.50	135.00	14.50	16.00	44.00	48.00
8	17.88	66.00	172.00	172.00	14.00	15.50	54.00	54.00
10	18.32	70.00	139.00	142.50	16.00	16.50	45.00	49.50
11	17.64	70.75	136.00	142.00	16.75	17.50	43.50	46.50
12	19.08	68.25	131.00	135.00	16.75	17.00	44.00	46.00
13	18.72	72.50	174.50	180.50	17.50	17.75	45.00	53.75

Note: * indicates substitution of group mean in place of missing data.

AGE, HEIGHT, WEIGHT, LEG LENGTH AND LEG GIRTH OF SUBJECTS
IN ECCENTRIC TRAINING GROUP

SUBJECT	AGE (yrs)	HEIGHT (ins)	WEIGHT (lbs)		LEG LENGTH (ins)		LEG GIRTH (cm)	
			Initial	Final	Upper	Lower	Initial	Final
14	18.40	71.50	164.50	166.00	16.25	17.50	48.50	50.50
15	19.16	68.50	127.00	132.00	15.50	16.50	43.50	47.00
16	18.48	72.00	155.00	156.00	17.75	18.00	45.50	50.00
18	19.40	67.75	153.50	160.00	16.00	17.00	48.50	54.50
19	24.48	69.75	150.00	149.00	16.00	16.75	52.00	52.00
20	18.08	67.75	172.50	172.50	16.75	15.00	50.50	52.50
22	18.16	71.50	144.00	149.00	17.00	18.00	47.28*	51.00
23	17.88	68.25	138.50	145.00	15.50	16.50	47.00	48.00
24	18.56	71.00	158.00	158.00	16.00	16.00	47.00	53.00
25	18.56	72.00	143.00	140.00	17.00	18.25	43.00	47.00

Note: * indicates substitution of group mean in
place of missing data.

AGE, HEIGHT, WEIGHT, LEG LENGTH AND LEG GIRTH OF SUBJECTS

IN ISOMETRIC TRAINING GROUP

SUBJECT	AGE (yrs)	HEIGHT (ins)	WEIGHT (lbs)		LEG LENGTH (ins)		LEG GIRTH (cm)	
			Initial	Final	Upper	Lower	Initial	Final
27	18.08	67.00	143.00	147.50	16.00	15.50	49.00	50.00
29	18.08	72.75	156.00	159.00	17.50	16.75	50.50	49.50
30	19.08	65.75	115.00	115.00	14.25	15.50	42.50	47.00
31	18.72	65.00	150.00	153.00	14.00	15.00	50.00	51.00
32	18.64	68.25	140.25	143.75	16.00	17.00	51.00	51.00
33	19.64	68.50	145.25	145.25	15.50	16.75	49.00	48.50
34	17.16	66.00	124.50	149.83*	15.00	15.75	45.50	47.50
36	19.64	68.00	132.00	140.00	15.50	16.25	45.00	46.50
37	18.88	71.00	153.00	159.00	16.00	17.00	47.00	50.50
38	18.40	69.00	183.00	186.00	14.75	16.75	58.00	58.00

Note: * indicates substitution of group means in place of missing data.

APPENDIX C

MEAN SCORES

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 80 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	165	138	200	176
4	95	69	77	59
5	101	125	197	128
6	108	90	99	138
7	176	168	117	107
8	89	92	89	54
10	104	92	98	74
11	62	32	35	68
12	80	68	104	78
13	78	59	110	87
ECCENTRIC				
14	104	51	99	75
15	131	117	98	147
16	116	123	111	86
18	141	138	69	117
19	84	78	65	89
20	101	81	116	122
22	110	96	95	102
23	68	108	96*	131
24	99	68	156	162
25	120	48	57	32
ISOMETRIC				
27	138	128	90	62
29	72	83	48	42
30	103*	69	93	78
31	173	219	137	101
32	89	74	96	78
33	68	60	45	63
34	101	104	86	81
36	98	125	96	117
37	84	104	137	87
38	103	95	138	173

Note: * indicates substitution of group mean in place of missing data.

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 90 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	182	162	224	192
4	80	87	95	68
5	137	168	242	144
6	125	93	141	179
7	174	183	129	116
8	99	116	102	71
10	135	123	122	120
11	60	56	45	78
12	125	81	126	92
13	72	75	140	98
ECCENTRIC				
14	116	56	125	83
15	131	140	128	182
16	122	123	149	96
18	152	153	92	140
19	81	60	81	87
20	143	108	141	146
22	116	104	92	122
23	147	132	126	170
24	179	98	173	162
25	138	72	102	35
ISOMETRIC				
27	126	183	86	69
29	83	93	71	54
30	56	105	98	101
31	197	258	167	146
32	113	87	116	101
33	80	68	50	77
34	101	122	102	84
36	105	131	114	168
37	90	138	197	137
38	156	129	156	200

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 100 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	207	182	252	222
4	96	116	123	96
5	161	198	287	216
6	149	101	183	206
7	182	200	176	137
8	93	144	128	92
10	170	153	159	188
11	81	84	113	65
12	141	107	153	113
13	84	99	159	131
ECCENTRIC				
14	122	69	156	104
15	185	168	144	234
16	140	146	177	123
18	203	165	107	200
19	84	96	120	120
20	177	137	174	192
22	129	128	107	165
23	174	170	170	188
24	197	150	198	186
25	159	99	129	80
ISOMETRIC				
27	204	233	134	90
29	96	137	105	74
30	72	141	132	131
31	269	275	212	173
32	129	110	144	108
33	78	102	80	116
34	108	147	141	96
36	132	185	146	221
37	122	179	228	165
38	179	138	216	228

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 110 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	233	212	288	266
4	107	156	179	123
5	198	245	374	255
6	177	114	243	269
7	209	236	236	167
8	125	204	176	123
10	254	183	191	222
11	125	104	144	87
12	171	125	210	176
13	110	167	183	183
ECCENTRIC				
14	147	86	230	110
15	207	204	177	282
16	165	179	231	170
18	201	200	137	267
19	99	138	158	162
20	201	155	210	266
22	156	185	150	249
23	209	224	207	254
24	219	162	236	219
25	191	137	195	104
ISOMETRIC				
27	246	278	173	149
29	117	182	183	162
30	99	215	177	180
31	300	281	258	185
32	149	122	204	138
33	105	149	122	149
34	131	177	183	120
36	161	249	209	287
37	155	242	309	224
38	230	165	266	315

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 120 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	221	267	332	335
4	132	231	279	168
5	225	279	435	299
6	219	158	308	327
7	242	272	311	207
8	149	263	239	153
10	314	224	231	242
11	155	182	188	68
12	203	152	246	227
13	185	206	186	240
ECCENTRIC				
14	192	134	293	179
15	227	278	207	366
16	214*	225	284	230
18	248	228	174	362
19	116	192	176	210
20	243	188	248	336
22	204	254	192	357
23	242	272	255	276
24	272	183	291	269
25	183	161	332	198
ISOMETRIC				
27	284	338	204	216
29	143	291	314	306
30	143	263	204	225
31	348	307	302	263
32	182	129	248	213
33	153	222	185	194
34	159	239	237	149
36	195	291	258	375
37	212	324	383	279
38	252	182	348	432

Note: * indicates substitution of group mean in place of missing data.

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 130 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	285	279*	435	383
4	140	303	494	299
5	249	363	530	323
6	255	197	390	410
7	291	317	347	281
8	188	330	327	189
10	347	264	290	279
11	203	273	281	191
12	266	197	366	309
13	287	267	252	327
ECCENTRIC				
14	275	180	396	237
15	287	327	270	498
16	269*	266	360	297
18	297	270	242	494
19	149	239	237	252
20	273	215	272	416
22	260	381	264	528
23	275	338	314	371
24	354	201	393	395
25	255	249	471	195
ISOMETRIC				
27	354	384	299	473
29	188	360	392	375
30	177	303	332	308
31	386	354	452	356
32	227	156	326	273
33	224	294	347	401
34	180	339	324	192
36	233	335	348	464
37	257	411	504	399
38	296	245	411	548

Note: * indicates substitution of group mean in place of missing data.

MEAN CONCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 140 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	320	333*	567	459
4	173	419	695	375
5	293	368	585	393
6	300*	191	437	513
7	368	384	374	312
8	225	369	413	275
10	386	321	380	308
11	269	348	324	260
12	291	261	458	431
13	371	333	284	434
ECCENTRIC				
14	336	248	462	332
15	330	348	330	657
16	320*	300	414	362
18	351	338	303	599
19	195	258	300	312
20	294	227	282	446
22	312	507	384	659
23	318	381	386	458
24	465	276	507	554
25	279	333	515	487*
ISOMETRIC				
27	407	464	396	593
29	252	429	497	567
30	236	402	411	389
31	482	419	539	435
32	260	182	404	351
33	293	351	437	518
34	242	339	443	257
36	285	363	426	527
37	303	510	638	482
38	344	326	587	764

Note: * indicates substitution of group mean in place of missing data.

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 80 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	257	398	249	350
4	278	168	257	252
5	294	254	401	339
6	185	170	204	267
7	212*	71	260	250*
8	209	165	153	266
10	257	230	201	270
11	141	110	132	78
12	162	78	245	250*
13	125	126	234	176
ECCENTRIC				
14	135	90	191	209
15	153	185	224	216
16	158	176	189	264
18	315	135	251	234
19	110	60	135	189
20	171	89	188	279
22	164	239	176	252
23	175*	230	210	288
24	201	194	185	215
25	168	204	179	170
ISOMETRIC				
27	242	255	209	198
29	119	179	182	173
30	86	189	201	180
31	210	104	195*	240
32	153	128	213	200
33	155	203	183	206
34	155*	155	165	234
36	128	171	117	201
37	149	122	209	287
38	155*	233	275	371

Note: * indicates substitution of group mean in place of missing data.

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 90 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	416	480	275	410
4	333	228	341	329
5	312	359	479	413
6	228	227	261	369
7	280*	231	350	132
8	260	204	180	344
10	287	302	216	293
11	254	176	176	140
12	230	129	296	294
13	204	183	288	207
ECCENTRIC				
14	111	147	222	263
15	224	236	269	260
16	243	219	242	330
18	368	231	290	320
19	150	98	171	236
20	210	182	242	339
22	210	264	192	294
23	245	255	258	347
24	230	246	206	276
25	197	221	216	183
ISOMETRIC				
27	326	297	261	228
29	137	242	236	222
30	105	222	231	222
31	272	213	66	288
32	170	155	282	245
33	179	365	257	249
34	147	183	203	267
36	176	210	147	266
37	204	239	243	359
38	282	258	326	441

Note: * indicates substitution of group mean in place of missing data.

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 100 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	512	560	362	596
4	395	264	441	399
5	336	459	570	533
6	341	309	353	474
7	105	308	492	207
8	335	254	255	399
10	369	378	228	308
11	320	242	303	251
12	332	194	359	335
13	372	299	351	266
ECCENTRIC				
14	185	191	284	329
15	272	284	394	359
16	273	261	296	420
18	438	303	344	383
19	203	113	234	269
20	243	230	308	419
22	275	336	200	360
23	293	350	332	434
24	303	266	261	354
25	222	270	255	218
ISOMETRIC				
27	431	348	306	281
29	183	336	276	282
30	162	267	284	264
31	329	311	237	398
32	215	179	333	300
33	204	255	299	336
34	258	231	239	308
36	245	290	186	323
37	245	272	318	441
38	363	333	429	542

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 110 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	596	695	453	749
4	509	335	542	506
5	437	533	698	632
6	416	411	480	615
7	240	408	672	291
8	404	332	333	552
10	468	485	291	375
11	446	341	410	396
12	380	272	431	392
13	440	452	428	344
ECCENTRIC				
14	222	248	444	434
15	368	357	366	449
16	377	327	405	545
18	524	366	431	485
19	273	170	338	386
20	315	300	383	536
22	347	467	251	510
23	384	432	447	519
24	399	296	335	452
25	284	315	323	288
ISOMETRIC				
27	552	480	389	317
29	219	417	389	248
30	234	381	332	324
31	449	383	384	504
32	285	203	396	374
33	282	423	381	470
34	309	267	344	383
36	318	404	245	422
37	329	339	411	612
38	374	365	497	690

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 120 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	686	842	567	930
4	614	449	747	549
5	603	650	882	837
6	447	557	603	848
7	338	524	846	428
8	497	356	435	731
10	515	620	383	440
11	588	509	596	494
12	483	318	579	593
13	614	593	554	513
ECCENTRIC				
14	374	299	509	546
15	498	476	468	626
16	455	429	510	644
18	689	474	489	611
19	380	275	434	488
20	416	356	479	671
22	464	620	348	626
23	516	537	546	678
24	513	357	420	587
25	335	438	387	375
ISOMETRIC				
27	677	606	536	401
29	282	563	509	527
30	261	488	392	416
31	585	506	635	630
32	333	233	461	518
33	312	423	524	636
34	266	321	464	450
36	341	528	339	587
37	443	497	483	836
38	510	522	666	839

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 130 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	767	936	729	1023
4	684	627	1139	725
5	561	726	912	989
6	480	783	836	1092
7	513	684	1058	653
8	560	479	642	803
10	524	705	398	527
11	671	774	836	782
12	533	423	717	633
13	686	719	735	719
ECCENTRIC				
14	504	363	578	734
15	735	645	650	876
16	585	558	597	660
18	749	654	623	764
19	446	414	432	677
20	444	419	564	767
22	534	714	491	788
23	533	521	594	873
24	509	465	572	735
25	447	585	494	459
ISOMETRIC				
27	660	728	624	548
29	383	704	606	728
30	410	524	482	516
31	744	612	765	755
32	375	288	530	699
33	369	587*	675	840
34	296	396	612	539
36	404	689	530	680
37	500	678	603	951
38	548	668	845	1044

Note: * indicates substitution of group mean in place of missing data.

MEAN ECCENTRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 140 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	750	711	944	869*
4	641	774	1121	998
5	558	830	889*	1086
6	323	794	999	1335
7	716	786	1202	869
8	624	522	833	518
10	216	788	375	512
11	521	935	980	1043
12	392	474	771	561
13	648	723	780	884
ECCENTRIC				
14	656	483	479	662
15	803	864	815	1226
16	638	648	597	884*
18	645	738	746	1022
19	455	557	369	810
20	473	396	572	671
22	629	720	638	801
23	318	449	605	951
24	574*	618	701	932
25	546	546	513	884*
ISOMETRIC				
27	572*	663	642	608
29	486	660	617	764
30	443	455	449	422
31	965	763	890	950
32	572*	324	504	798
33	489	651*	777	980
34	572*	480	584	599
36	398	818	581	699
37	519	776	797	1154
38	701	918	957	1294

Note: * indicates substitution of group mean in place of missing data.

MEAN ISOMETRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 70 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	197	249	189	242
4	165	179	156	141
5	188	188	215	179
6	165	137	129	150
7	260	209	195	240
8	330	201	194	171
10	156	206	188	143
11	105	104	116	158
12	110	117	116	126
13	159	117	125	185
ECCENTRIC				
14	132	174	110	140
15	101	125	131	153
16	141	200	167	135
18	173	221	239	174
19	146	126	84	138
20	261	138	131	186
22	113	158	150	164
23	221	201	186	237
24	213	197	186	200
25	141	116	152	150
ISOMETRIC				
27	174	116	158	98
29	189	156	114	188
30	125	131	117	128
31	252	213	110	221
32	111	92	102	150
33	156	141	141	213
34	179	84	153	134
36	167	114	144	131
37	135	183	161	161
38	272	224	225	218

MEAN ISOMETRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 110 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	459	378	336	242
4	296	228	450	141
5	314	390	368	179
6	374	297	290	150
7	342	281	465	240
8	281	225	231	171
10	396	323	423	143
11	215	231	300	158
12	345	237	278	126
13	311	309	266	185
ECCENTRIC				
14	345	231	309	140
15	369	225	282	153
16	351	293	263	135
18	333	210	291	174
19	285	266	215	138
20	261	257	294	186
22	269	299	225	164
23	416	506	323	237
24	377	267	306	200
25	339	303	430	150
ISOMETRIC				
27	354	245	251	98
29	230	372	251	188
30	191	240	272	128
31	337	368	254	221
32	261	141	345	150
33	191	245	242	213
34	171	210	221	134
36	314	278	275	131
37	279	287	299	161
38	300	323	392	218

MEAN ISOMETRIC STRENGTH SCORES FOR
SUBJECTS IN CONCENTRIC, ECCENTRIC AND ISOMETRIC
TRAINING GROUPS AT A KNEE ANGLE OF 150 DEGREES

SUBJECT	TEST 1	TEST 2	TEST 3	TEST 4
CONCENTRIC				
2	578	740	758	1035
4	737	882	1116	909
5	384	348	524	579
6	371	396	573	1073
7	843	797	524	729
8	501	647	678	1035
10	585	911	792	876
11	276	831	719	1167
12	660	354	750	503
13	905	615	882	1107
ECCENTRIC				
14	675	696	584	834
15	1001	755	837	966
16	648	629	716	814
18	795	546	813	833
19	425	482	626	962
20	528	308	393	762
22	597	599	815	1103
23	552	738	627	702
24	942	885	689	1166
25	795	725	719	855
ISOMETRIC				
27	606	582	530	800
29	605	732	563	1349
30	531	675	677	666
31	969	780	902	1136
32	383	302	558	717
33	569	669	744	1014
34	158	692	503	594
36	738	683	681	728
37	1067	827	1175	1311
38	585	894	998	1073

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